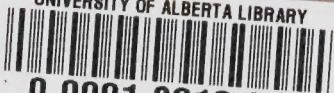


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**EFFECT OF CROWN COVER AND SLASH DENSITY
ON THE RELEASE OF SEED FROM
SLASH-BORNE LODGEPOLE PINE CONES**

by

D. I. Crossley

ONE

FOREST RESEARCH DIVISION

TECHNICAL NOTE No. 41

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Effect of Crown Cover and Slash Density on the Release of Seed from Slash-Borne Lodgepole Pine Cones

Project A.27

by

D. I. Crossley

INTRODUCTION

In all harvest cuttings the regeneration of the stand is a major consideration that is usually complicated by the unpredictable periodicity of seed crops. One of the major advantages in managing lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) is the fact that most of the trees in stands of harvestable age bear their cones, or the majority of their cones, serotinely, so that the forest manager has a continuous supply of seeds in the stand crowns awaiting his husbandry. Under natural conditions this storehouse of seed ensures our forest lands against denudation after fire; the heat of the fire serves to melt the rosin bond that seals the cone scales together, and so permits the gradual flexing of the scales to release the stored seed after the fire has subsided. Cultural practices, however, usually preclude the use of prescribed burning as an aid to regeneration since adequate safeguarding makes it too expensive a silvicultural tool in some areas. It is the purpose of this study to investigate the natural release of stored seed from cones borne in slash laid down under various cutting methods.

LITERATURE REVIEW

Clements (1910), after immersing cones in hot water, made the following observations with respect to the opening of the serotinous cones of lodgepole pine: (i) the cones crack open as a result of the softening of the rosin bond which holds the scales together at their tips; (ii) temperatures of 45° to 50°C. will crack open most cones but they rarely open up enough to loosen all seeds at a single drying; and (iii) in order to spread the scales sufficiently to loosen all the contained seeds, alternate moistening and drying is necessary. He also noted that temperatures below 40°C. were insufficient to open serotinous cones, and that a temperature of 69°C. would crack open almost all of them immediately.

Cameron (1953) made a study using the basic approach of extracting the bonding material with petroleum ether, and evaporating off the terpenes. The melting point of the residual rosin was then determined. Six cones were so treated and the melting point of the rosin was found to vary between 44.5°C. and 49.0°C., with the mean being 45.3°C. Thus Cameron's technique for determining the melting point of the bonding rosin provides very similar results to those arrived at by Clements with his method of water immersion.

Because of the stored seed available and waiting to be released from the serotinous cones in lodgepole pine slash, it appears necessary only to increase the temperature to a point where the rosin bond ruptures, and then to await the natural alternate wetting and drying of the cone until the scales spread

sufficiently to allow the majority of the seed to fall out. LeBarron and Roe (1945) maintain that practically all jack pine seed can be shaken from a cone when the scales have been separated only one-eighth to one-quarter inch, and since the cones of the two species are so similar there is little reason to believe that the same thing would not be true for lodgepole pine under similar conditions. However, shaking introduces a physical force that does not usually occur in slash under natural conditions, and it is therefore likely that a considerably wider spread of the cone's scales would be necessary to release a high percentage of the seed. Natural weather conditions will provide the necessary wetting and drying once the bonding effect of the rosin has been overcome, but it seems that in Alberta latitudes special conditions may have to be created before the heat of the sun is sufficient to bring the cone's rosin bond to the critical melting temperature.

Rupture of the rosin bond requires a temperature in the neighbourhood of 45°C. This will be referred to here as the "critical temperature". Bodies hotter than this are the only sources from which heat can come to raise the temperature of the cone to this point. This limits the sources to: (i) the sun; and (ii) bodies that have been heated hotter than this critical temperature by the sun.

The mode of transfer of incoming heat is almost exclusively by radiation; conduction and convection require an intermediate body as a carrier, and in the carrying process the intensity of the heat will generally drop below the critical temperature level unless the transfer distance is very small, say one-tenth of an inch.

The most obvious and only practical source of heat is that provided by the sun, through the media of radiation, convection and conduction. Reduction in intensity of radiation received near ground level depends on such factors as cloud, haze and smoke. The amount by which the intensity of sunshine is diminished as it passes through the atmosphere depends on two factors: (i) scattering by air molecules; and (ii) absorption. The amount of scattering will depend upon the length of path through the atmosphere; it will be least when the sun is high in the sky, and at high altitudes. The amount of absorption depends almost entirely on the water vapour content of the atmosphere, and may vary from 6 per cent to 13 per cent of the incoming radiation. Therefore sunshine will be more intense in the mountains at lower altitudes, and when the area is covered with a dry (usually cool) air mass.

Any object suspended in free air a short distance above the surface of the ground, with no direct contact with any material other than air, is subject to the heat exchange illustrated in Figure 1. It will be noted that this diagram presents an approximation of conditions on a day when there are clouds in the sky. However, on a clear day, with the sun at its zenith, the total loss from the solar beam down to the surface of the ground is only slight. In any event a cone suspended in the air close to the surface of the ground gains a large percentage of its heat from solar radiation, and from long-wave terrestrial radiation from the ground and solid objects not too far distant.

As the temperature of the suspended cone rises the rate at which it loses heat to its surroundings (by radiation, convection and conduction) rises. Its temperature will continue to rise until its rate of loss of heat exactly equals the rate of heat income. The rate of heat income is largely beyond human control, being dependent on the intensity of the sun's radiation. Minimizing rate of heat loss is the key to obtaining high temperatures.

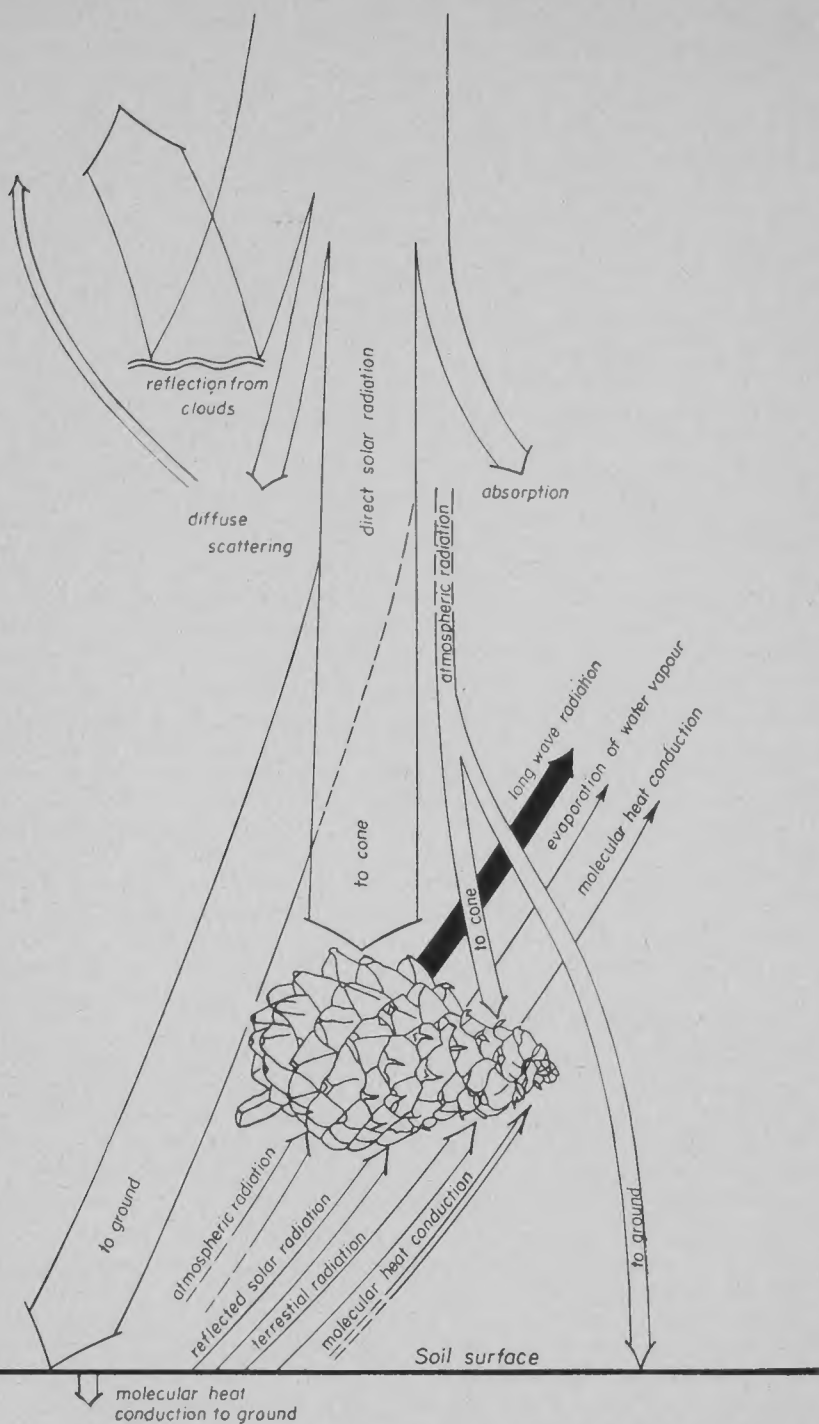


FIGURE 1.—Heat exchange at noon about a cone suspended in still air a short distance above the ground.
Width of arrow approximates amounts of heat transferred.
(Modified from Geiger (1950))

Heat loss by radiation will be kept to a minimum if the bodies around the cone with which it tends to come into radiative equilibrium are also irradiated by the sun and raised to a similar temperature. Heat loss by conduction and convection depends on the temperature gradient surrounding the cone. If the volume of air around the cone is small compared with the surface area of bodies exposed to sunshine, conduction from these bodies will soon heat this volume of air, and the gradient of temperature around the cone will be minimized. But when the temperature of any parcel of air reaches the critical temperature ($45^{\circ}\text{C}.$), with the surrounding free air at ordinary summertime temperatures, (say $80^{\circ}\text{F}.$), thermal instability will be intense. The hot air tends to rise and be replaced by much cooler air. Minimizing conduction and convection heat loss therefore depends upon minimizing the air ventilation that results from thermal instability.

The conditions described for minimizing heat loss, both radiative and also conductive and convective, are more usually met close to the ground. As the sun's radiant energy strikes the surface of the ground, most of it is absorbed and serves to raise its temperature, and a portion of it is reflected from its surface. Geiger (1950) emphasizes that the temperature conditions of the layer near the ground are determined by the immense amount of heat which the surface of the ground absorbs. Heat is conducted from the surface to the deeper layers of the ground, but the greater portion serves to heat the air layer near the ground. From this significance of the earth's surface for heat exchange Geiger concludes that the highest temperature about noon is at the boundary between ground and air; starting from here the temperature decreases upward and downward.

The temperature of the irradiated ground rises at the same time as the cone temperature, but usually to a somewhat higher level, and a small amount of heat will be transferred from ground to cone. However, the function of the ground is primarily to prevent heat loss rather than to supply heat income to the cone. Perhaps the biggest assist towards rupturing of the cone's rosin bond conferred on it by proximity to the ground is the consequent minimizing of ventilation. Warm air around the cone can hardly be blocked from rising without cutting off the sunshine, but the same purpose is served by making difficult the entry of cooler air to replace it. At the same time the strength of the wind is an important consideration. According to Geiger the wind is usually at a maximum about mid-day, but directly at the surface of the ground the air is almost entirely at rest, and cones at this level experience a minimum of heat loss by conduction and convection.

Incident light strikes the upper surface of a cone at right angles over a very small portion of its area. The remainder strikes at "grazing" angles so that the effect of solar energy is greatly decreased. Thus, only a very small portion of the upper surface of a cone is at any time exposed to the maximum effects of direct solar radiation. The remainder or lower surface of the cone is spherically irradiated in varying degrees from sources other than the sun's disk.

The amount of a cone's surface that is illuminated by the sun depends a great deal on its shape. Thus, if the cone is situated so that its main axis is parallel to the rays of the sun, the cone will intercept the same amount of solar energy whether the flat base or the pointed top end is facing the sun. In the latter position a great deal more surface area is illuminated and the intensity of illumination is proportionately decreased with lower resultant temperature. In addition, it should be pointed out that the roughness of a cone's surface may contribute to the heat developed, in that such roughness serves to concentrate the heat in the hollows and raises the temperature of the rosin bond in these areas to a critical level sooner than if the cone surface were smooth.

To summarize, the cone affixed to slash on the forest floor will attempt to come to a heat balance with its changing environment, and the equilibrium temperature it will reach will depend upon a number of factors. They include:

1. The amount of direct and reflected solar and atmospheric radiation received, which will in turn vary directly with the altitude, the position of the sun in relation to its zenith, the nature of the air mass covering the area, and the degree of crown canopy.
2. The intensity of illumination per unit area of the cone.
3. The amount of terrestrial radiation which will depend upon the height of the cone above the ground and the proximity of neighbouring, solid objects such as branches and foliage.
4. The heat lost through long-wave radiation from the cone.
5. The heat lost through conduction from the cone to the air enveloping it. This is a variable source of heat loss since the greater the exposure to ventilation and the greater the air movement, the greater such a loss will be.

METHODS AND MATERIALS

The field study to investigate the effect of crown cover and slash density on the release of seed from slash-borne lodgepole pine cones was divided into two phases. They were:

1. A fundamental study of comparative cone tissue temperatures reached throughout the day under maximum conditions of solar radiation by cones situated at various levels above the ground.
2. An applied study of the behaviour of slash-borne cones in relation to seed release.

The investigations were undertaken in an 85-year-old lodgepole pine stand at Strachan, Alberta, ($52^{\circ} 15'N$, $115^{\circ} 07'W$) at an elevation of approximately 3,500 feet. Previous cutting studies (Crossley, 1955) had been established in this block of timber.

The fundamental study is described and discussed first, although both investigations were carried on simultaneously.

Phase 1. Cone Tissue Temperature Study

a) *Instrumentation*

The measurement of tissue temperatures in biological studies is usually undertaken with fine wire thermocouples embedded within the tissue and connected to a potentiometer. Such an instrument provides instant temperatures whose accuracy largely depends upon the correct mounting of the thermocouples. According to Eggert (1946), the thermocouple junction must be isolated in such a way as to eliminate any extraneous conduction of heat to or from that point that results from the mechanics of its installation. In this study, however, it was not considered vital to obtain exact cone tissue temperatures. An installation that would provide approximate yet consistent results would answer the question of comparative temperatures reached at different levels above the ground, and preliminary investigations of thermocouple mountings were made in order to develop a satisfactory procedure.

Using a flattened needle, a fine hole was drilled into a cone scale on each cone to be studied. An inch of each lead at the end of a 6-inch piece of 36-gauge copper-constantan wire was bared, scraped of enamel, twisted together and fused with the heat of a match. This junction was inserted into the drilled hole, and

since the temperature recorded by the thermocouple is that which exists at the first point of contact of the copper and constantan leads, care was taken to see that this was located just below the surface of the cone scale. Cone scale fillings from other cones were then dropped into the opening around the junction and packed as tightly as possible. A steep temperature gradient affecting the thermocouple leads within the first inch or two from the junction could result in a large conductivity error and, in order to reduce it as much as possible, the leads were brought into continuous contact with the surface of the cone through channels cut in its surface with a fine coping saw. The fibre-glass covered leads were carried to the back of the cone and fastened rigidly to it with a spot of black glue. Two or three inches of wire remained free with leads bared to provide contacts with the potentiometer leads.

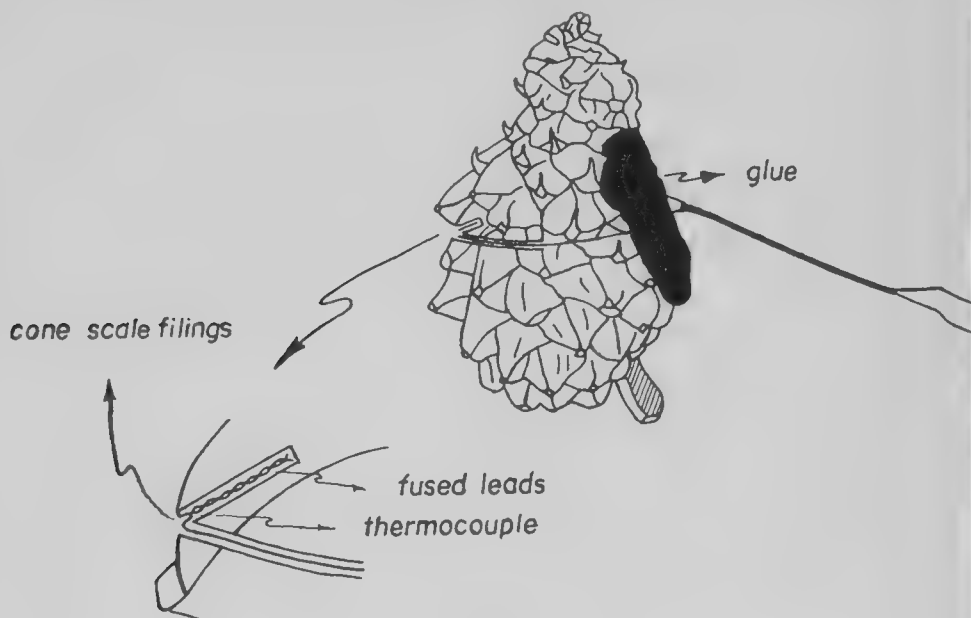


FIGURE 2.—Thermocouple installation.

In order to obtain temperature readings, 26-gauge leads from a Rubicon potentiometer were brought into contact with the 36-gauge thermocouple leads.

The prepared cones were mounted at different levels on wooden stands (Plate 1). The inverted troughs were designed as covers to shade the cones, and were removed whenever a temperature run was in progress. The 36-gauge leads from the cones were stapled to the wooden uprights and were brought into contact with the leads from the heavier 26-gauge wire from the potentiometer whenever a reading was desired.

b) *Efficiency of Instrumentation*

This equipment was designed to obtain fundamental information on comparative temperatures of cone tissues reached at various levels above the surface of the ground. In order to test the efficiency of the instrumentation a number of preliminary temperature runs were made. These were designed to investigate the reliability of thermocouple installations, and the importance of cone position in relation to the changing position of the sun.

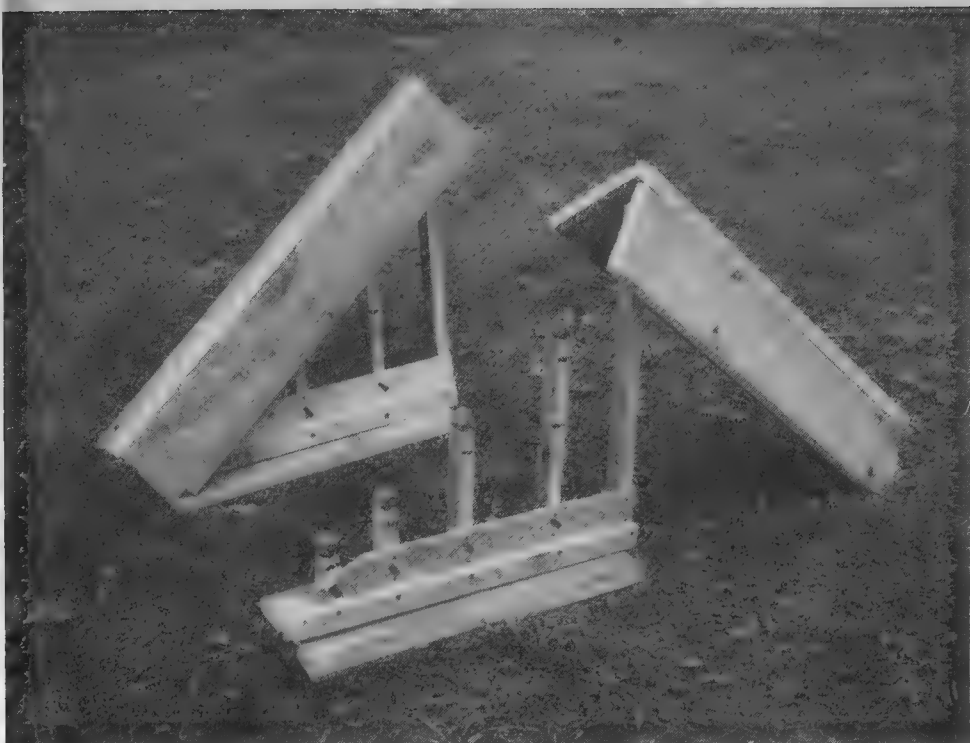
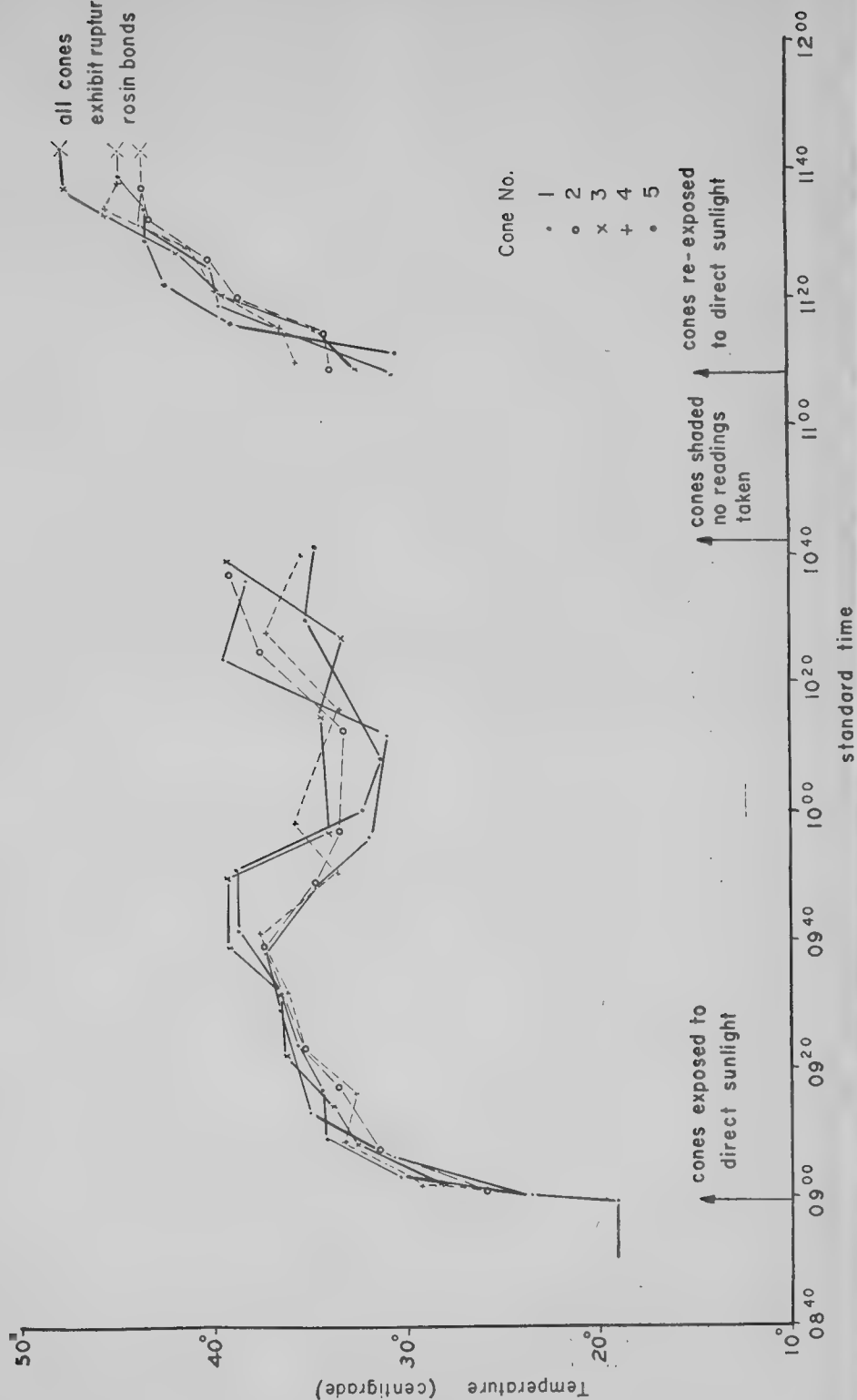


PLATE 1.—Sheltered and unsheltered cones on stands.

(i) *The Effect of Method of Thermocouple Installation in the Cone.*—In order to study the effect on the recorded temperatures of the method of thermocouple installation previously described, a comparison was made with other less fastidious methods. Five cones were variously prepared for study and all were placed at the same level on a cardboard base in direct sunlight. Cone No. 1 was prepared as outlined in the description of Figure 1, with the junction buried by packing the hole which contained it with cone fillings. Cones No. 2 and No. 3 were left without such packing—that is, the junction was placed below the surface of the hole but it was otherwise visible. Cone No. 4 was treated similarly to cones No. 2 and No. 3, except that the leads from the junction were left bare of fibre-glass insulation for an inch or so. In cone No. 5 the junction was left exposed just outside the surface level of the drilled hole. The temperature run on these five cones commenced at 8:40 a.m. on August 4th, at which time the temperature of each cone was read while it was shaded. At this time all thermocouples read 19°C . At 8:59 the cones were placed in direct sunlight and temperatures were read steadily until 10:40. At this time the cones were again shaded and temperature reading did not recommence until 11:08 when they were again exposed to direct sunlight. The results of these recordings are presented in Figure 3.

All cones exhibited a rapid and fairly uniform increase in temperature as soon as they were exposed to direct sunlight. The uniformity in readings continued for about 40 minutes; the following hour, however, showed considerable fluctuation, with none of the readings obtained consistently related to the others. Readings were then discontinued and the cones shaded for 26 minutes. During this time cone temperatures dropped somewhat, but when they were again



subjected to direct sunlight the temperatures climbed rapidly and fairly consistently until the rosin bonds ruptured about 11:40. These cones were then discarded and a similar set of five prepared for afternoon readings. The results of this run are presented in Figure 4.

The shaded cones were exposed to direct sunlight at 13:25. Initial warm-up was rapid to a point of levelling off slightly above 40°C., and during this time all cones ruptured their rosin bonds. Readings remained fairly consistent after the initial warm-up, with the exception of those obtained from cone No. 5. Here the readings fell off immediately after rupturing occurred. Examination of the cones themselves (Figure 5) revealed the reason for this unexpected behaviour. Only in cone No. 5 did rosin bond rupturing directly effect the thermocouple. In this instance the spreading of the cone scales laid bare the wire junction, and resulted in an immediate drop in the temperature reading.

While there may be some doubt that each thermocouple accurately recorded the temperature of the cone tissue in its immediate vicinity, the results from cone to cone in these series of temperature runs appear to be consistent and therefore the readings provide us with the comparisons desired. From the results obtained it would appear that it was not necessary to be too fastidious about the installation of thermocouples.

(ii) *The Effect of Thermocouple Position in Relation to the Sun.*—In order to investigate the effect of the position of the thermocouple in relation to the sun, another series of tests was conducted on prepared cones. In this case each cone had a battery of three thermocouples, two on opposite sides of the main body of the cone, and a third near the tip. When placed for temperature study, junction No. 1 was positioned on a plane at right angles to the sun's source, No. 2 exposed to direct radiation but at a "grazing" angle, and No. 3 unexposed to direct radiation (Figure 6).

Two cones "A" and "B" were used in this study, one large and one small, and a run of approximately one hour was conducted in the morning. Two more cones "C" and "D" were similarly prepared and a run completed in the afternoon of the same day. The results of these temperature runs are presented in Figure 7. The numbers 1, 2, and 3 represent the thermocouple positions illustrated in Figure 6.

The results from large cones "A" and "C" were quite similar. Thermocouple No. 1 in each case reached consistently higher temperatures than thermocouples No. 2 and No. 3, and both thermocouples No. 1 and No. 2 reached considerably higher temperatures than thermocouple No. 3. Maximum temperatures were reached when the cone was exposed to both direct and indirect sources of heat. Thermocouple No. 3 was so situated that the amount of heat received from direct solar radiation was dependent upon the coefficient of conductivity of the cone itself, and the lower temperatures recorded at such junctions indicate that this coefficient is low.

The same thing is apparent in temperature runs conducted on the small cones. However, in both cones the temperatures reached by thermocouples No. 1 and No. 2 were not distinctly different as they were in the larger cones. This may be due to their smaller bulk.

From the results obtained it can be inferred that a cone's thermal conductivity is not high. This agrees with the results presented in Figures 4 and 5, and it is therefore apparent that the rosin bond must rupture in close proximity to the thermocouple, otherwise the temperature recorded can have little relation.

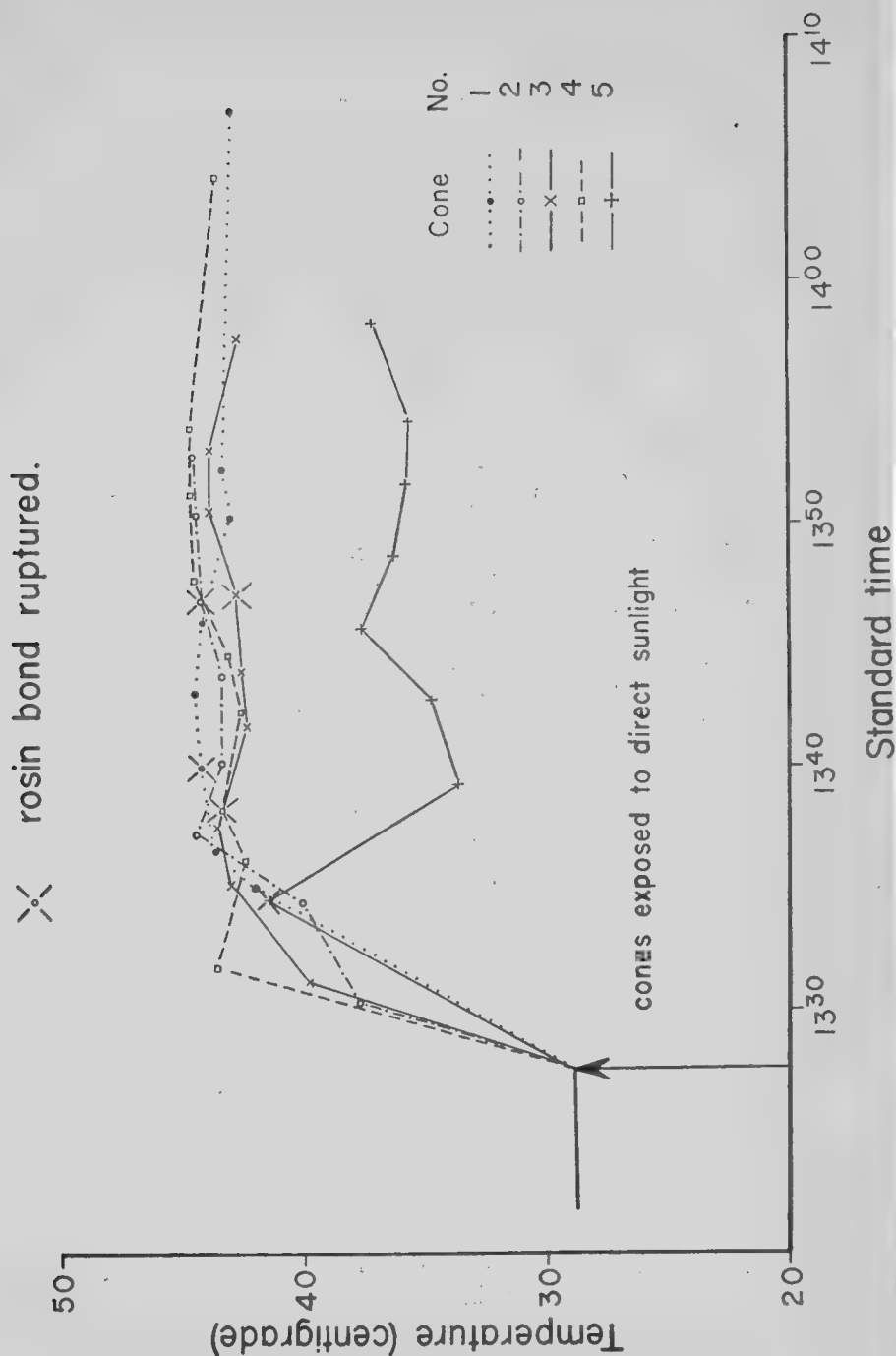
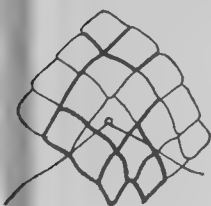
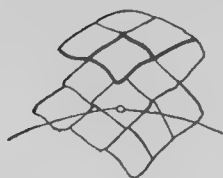


FIGURE 4.—The influence of thermocouple attachment on cone temperature recorded during the afternoon (Aug. 3rd.)

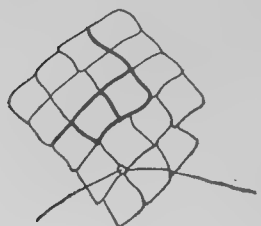
Cone 1



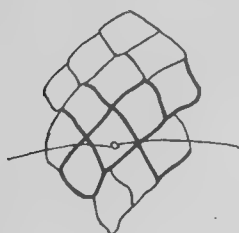
Cone 2



Cone 3



Cone 4



Cone 5

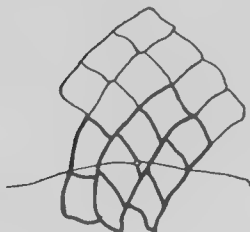


FIGURE 5.—Pattern of rosin bond rupturing in vicinity of thermocouple insertion.

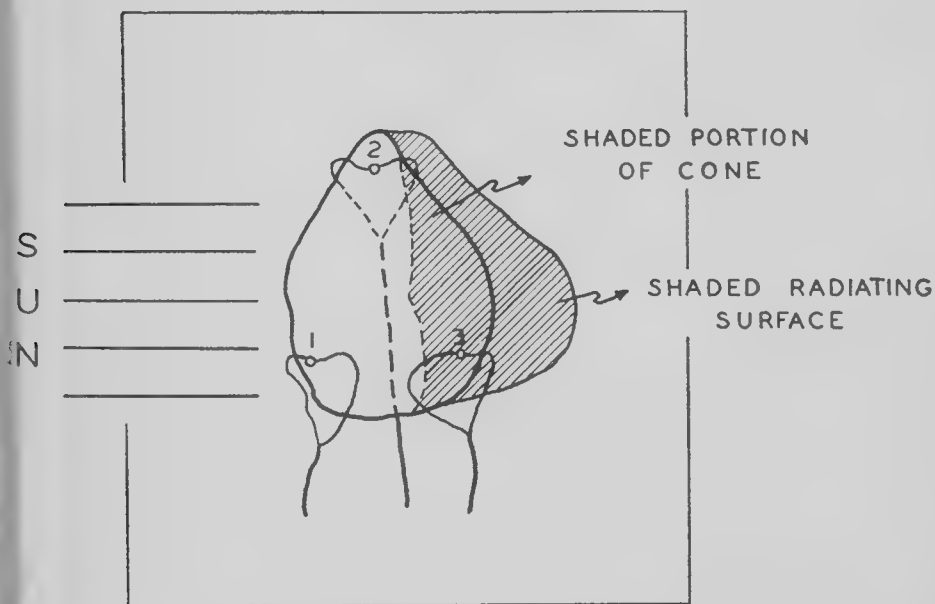


FIGURE 6.—Battery of thermocouples.

c) *The Rate of Heating*

It is interesting to note from the curves presented in Figure 7 the rapid rise in temperature among all four cones as soon as they were subjected to direct sunlight. The temperature recorded by thermocouple No. 1 in cone A rose from 23.5°C. to 46.5°C. in 17 minutes, and to 50.5°C. in 31 minutes, increases of 23° and 27°C. respectively

Rosin bonds surrounding thermocouple No. 2 in cone B and thermocouple No. 1 in cone C ruptured at 42°C. and 47.5°C. respectively. Other thermocouples registered similar or even higher temperatures without the neighbouring bonds rupturing, thus indicating either errors in recorded temperatures, or differences in melting temperatures on different cones or different surfaces of the same cone. The fact that thermocouple No. 1 in cone A registered 50.5°C. without any sign of rosin bond rupturing was disquieting. To investigate this further, cones A and D, whose rosin bonds were still intact, were immersed in water at a later date and the temperature raised until rosin bonds cracked. In both cones this occurred at 53°C.

d) *The Constancy of Tissue Temperature Readings*

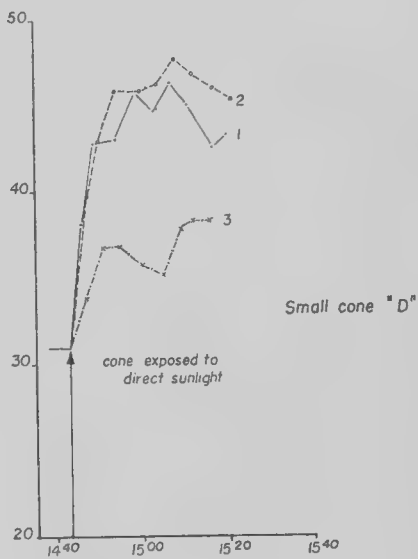
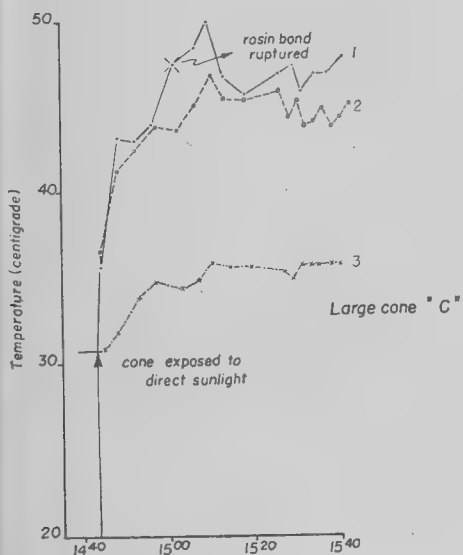
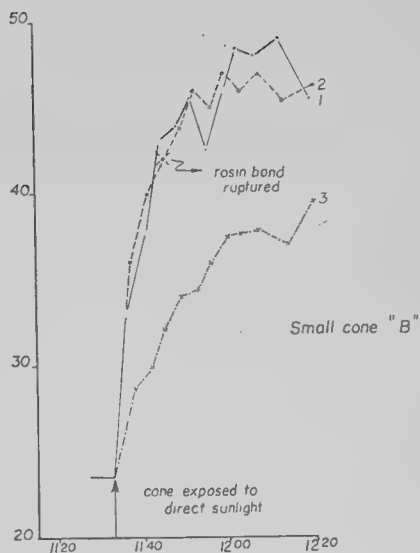
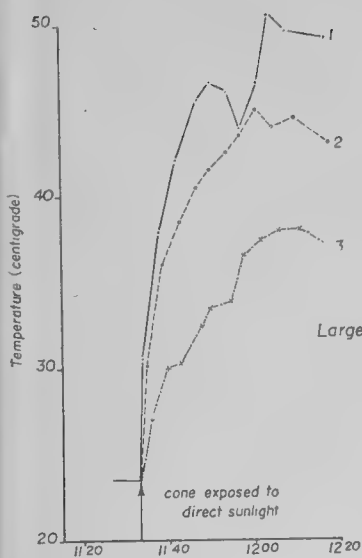
The next exploratory runs were conducted for the purpose of comparing the variation in cone temperature when all cones were situated at one level on the ground, with the variation experienced among the same cones when they were elevated to varying levels above the ground. (Actually this order was reversed in the field.) The results are presented in Figure 8. When the variant of height above ground was not introduced, similarly exposed thermocouples in different cones were inconsistent in their recording of temperatures. It is therefore suggested that the rather limited temperature variations experienced when the cones were elevated to varying heights above the ground would have been greater if each cone or cone thermocouple had had similar heating characteristics. For example, thermocouple No. 1, with relatively low heating characteristics has nevertheless exhibited the highest temperature due to the cone's proximity to the ground. Had a cone or thermocouple with heating characteristics similar to cone No. 4 been placed at the 2-inch level it likely would have exhibited an even higher temperature than cone No. 1. The erratic behaviour of cone No. 4 when at 12-inch level is explained by the fact that this cone ruptured its rosin bond in the previous ground-level run.

The results of this series of temperature runs indicate a variation in recorded temperatures despite similar preparation and orientation of cones, and suggest the necessity of multiple readings on a number of prepared cones.

e) *Preliminary Results*

From the preliminary investigations made, the following points became apparent and would need to be taken into account in the proposed study of cone tissue temperatures in relation to height above ground.

- (i) Since the study sought to determine the relationship between the temperature of cones situated at varying distances above the ground and not their absolute temperatures, the method of installation of the thermocouple was not critical.
- (ii) The rosin bond must crack in the immediate vicinity of the thermocouple before it could safely be related to the temperature recorded.
- (iii) If consistent cone tissue temperature readings were to be obtained that could be related to one another with any degree of confidence, all thermocouples must be similarly oriented in relation to the sun, and that orientation maintained throughout the duration of the run.



Standard time

FIGURE 7.—Temperature relationships resulting from three similar thermocouple positions on each of four cones.

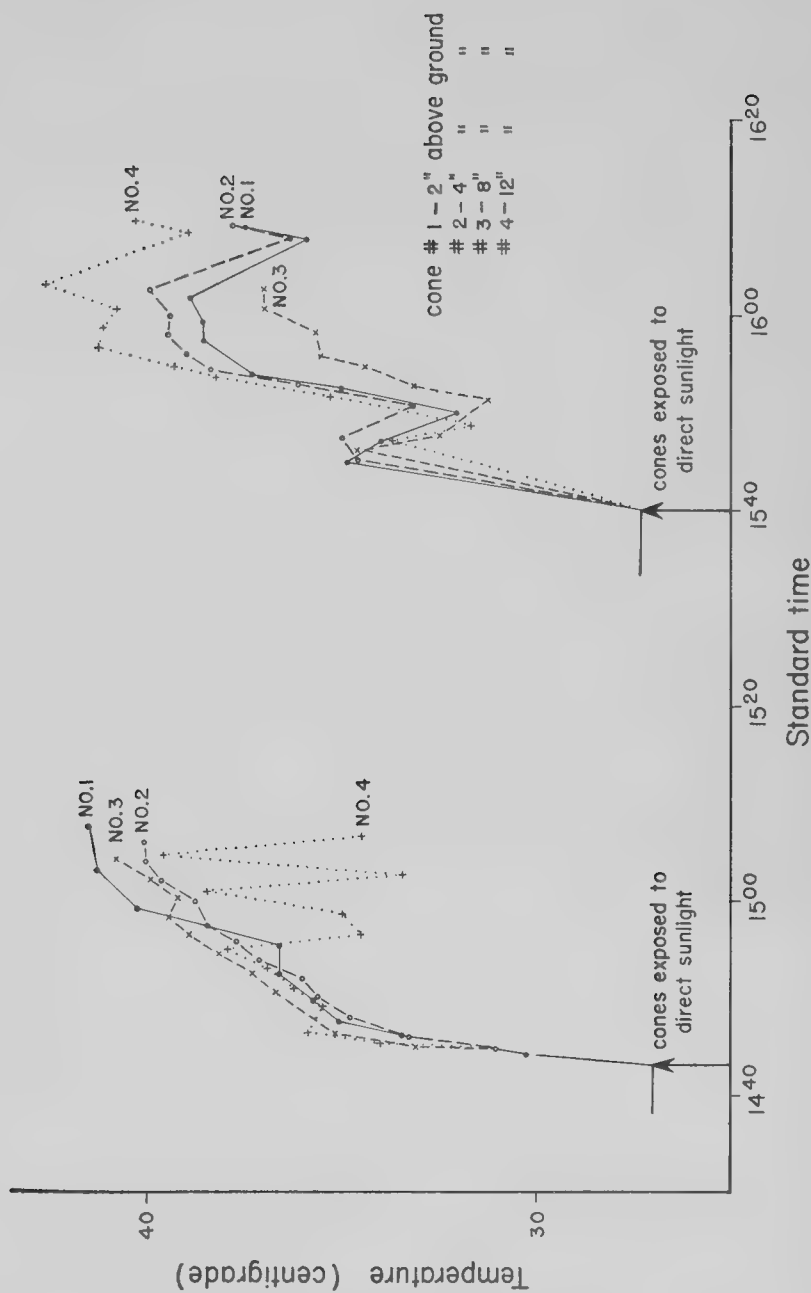


FIGURE 8.—Comparative temperatures reached by the same set of four cones.
 1st—at various levels above ground 2nd—at ground level

- (iv) Thermocouple temperatures rise very rapidly once the junctions are under the influence of direct solar radiation. Therefore intermittent sun, resulting from periodic cloudiness, would introduce undesirable variations in the readings.
- (v) Because of variations within cones, or their thermocouple installations, multiple readings from several cones would have to be taken in order to average discrepancies in temperatures.

f) *The Modified Temperature Runs*

Keeping in mind the limitations outlined above, a series of temperature runs was designed to answer the original question of the relation between cone tissue temperature and height above ground.

Four sets of 5 cones each were mounted on prepared cone stands as illustrated in Plate 1. In each case the placement of thermocouples was standardized in the manner presented in Figure 2. The four stands were mounted on a wooden floor placed in the open, and in such a way that none cast a shadow on any of the others. Over the top of this floor, reddish-brown mineral soil was sprinkled to a depth of 2 inches. The use of the wooden floor permitted the investigators to quickly and readily maintain correct orientation with the sun. Reorientation was undertaken every ten minutes.

At the base of the first cone stand, one thermocouple was placed immediately below the soil surface: the prepared study-cones on all four stands were situated 1.5 inches, 3.5 inches, 6.5 inches, 10.5 inches, and 16.5 inches above the surface of the soil.

The field instrumentation and recording crew are shown in Plate 2.



PLATE 2.—Recording cone temperatures in the field.

In order to obtain a record of air movement during the period of temperature observation, a Short and Mason hand anemometer was mounted on a stand 6 inches above the ground and its readings recorded every 2 minutes. Air movement was light and variable during the run and in order to keep the anemometer correctly oriented with the changing airflow, a smoke pot was set up. The observer kept the anemometer oriented with the direction of smoke movement.

The first run commenced at 10:50 on August 15th, and with the exception of a short interval at noon, continued uninterrupted until 16:50. The day was cloudless and wind velocities were light, varying from 0.6 to 2.8 m.p.h. The maximum air temperature reached during the day was 81°F. (27.2°C.) recorded in a standard instrument shelter located in a nearby opening. Throughout the run, 28 readings were taken on the ground thermocouple, and 28 on each of the cones, making a total of 588 individual temperature readings in 5 hours and 30 minutes, or an average of one reading every 33.8 seconds. Temperature readings from all 4 cones at each level were averaged and the results are presented in Figure 9. Two cones ruptured their rosin bonds during this run, both at 45.2°C.

It is interesting to note from observation of the curves presented in Figure 9 the lack of any pronounced temperature peaks. The greatest range in average temperatures is exhibited by the cones at 1.5 inches above the ground, and varied from 37°C. to 45.5°C. during the 6-hour duration of the run. The maximum temperature of 45.5°C. occurred at this level about 2 p.m., and the average temperature for a 1-hour period was the same between 1:00 p.m. and 2:00 p.m. as it was between 2:00 p.m. and 3:00 p.m.

TABLE 1. AVERAGE CONE TISSUE TEMPERATURE READINGS AT VARIOUS LEVELS ABOVE THE GROUND ON AUGUST 15TH

	6-hour run	1-hour run	Max. reading
	(1050 — 1650 hours)	(1300 — 1400 hours)	
Ground.....	43.3°C	47.3°C	51.5°C (1521 hrs.)
1.5".....	42.1°C	43.8°C	45.5°C (1403 hrs.)
3.5".....	40.0°C	41.2°C	42.8°C (1310 hrs.)
6.5".....	37.1°C	38.0°C	39.3°C (1443 hrs.)
10.5".....	35.4°C	36.6°C	37.3°C (1358 hrs.)
16.5".....	35.6°C	36.4°C	37.4°C (1400 hrs.)

The results presented in Table 1 are shown in Figure 10 in the form of temperature gradients.

An analysis of variance was undertaken to test the importance of the distance above ground level.

1. 6-hour run

Source of var.	D. of F.	Ss	Mean Sq.	F ratio	Significance
Blocks.....	3	11.36	3.79	1.69	not sig.
Treatments.....	4	141.49	35.37	15.79	highly sig.
Error.....	12	26.86	2.24		
Total.....	19	179.71			

2. 1-hour run

Blocks.....	3	10.5	3.50	1.65	not sig.
Treatments.....	4	164.8	41.20	19.16	highly sig.
Error.....	12	25.8	2.15		
Total.....	19	199.1			

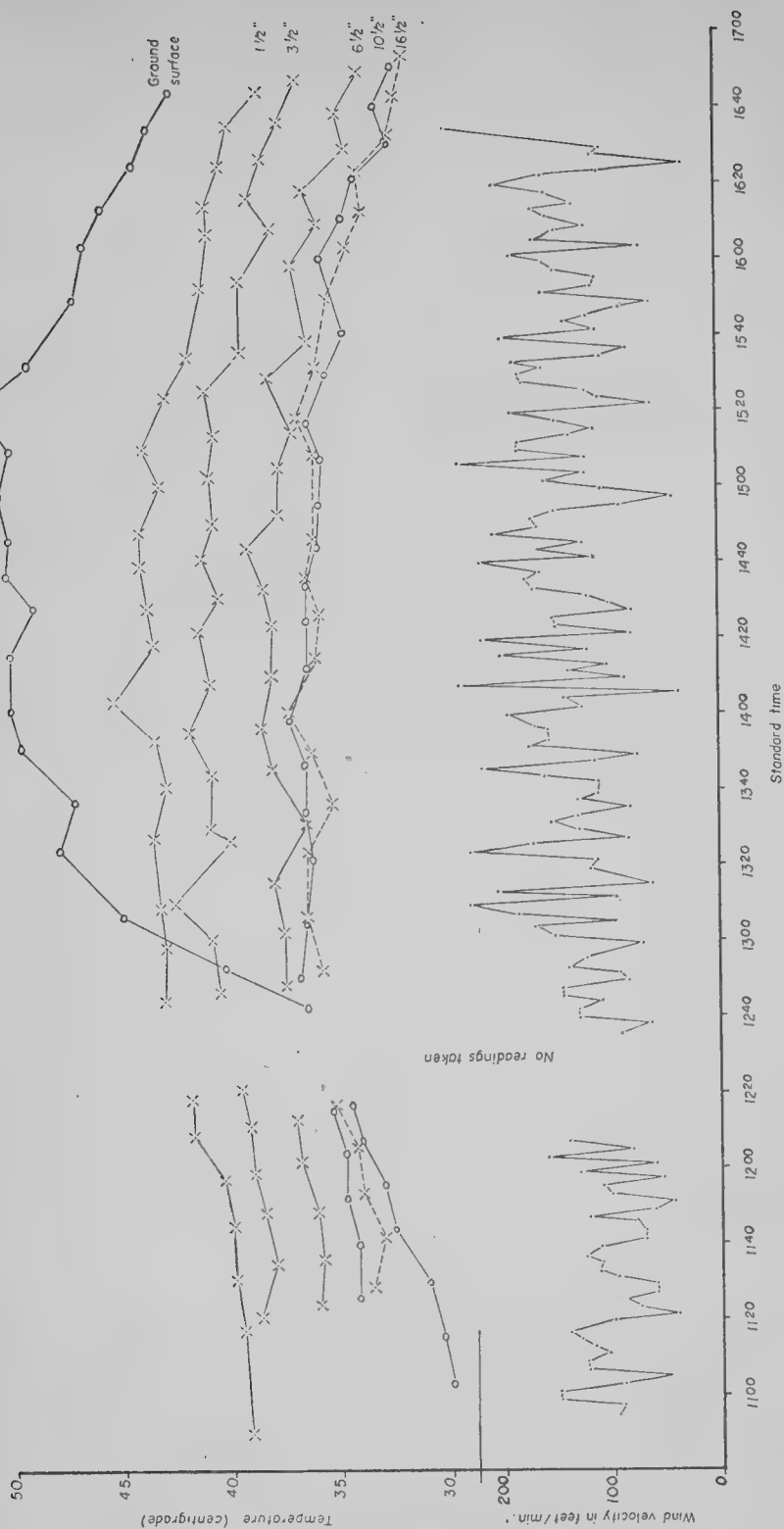


FIGURE 9.—Average temperatures of cones situated at various levels above the ground and exposed to direct sunlight throughout the day (Aug. 15th), together with corresponding wind velocities.

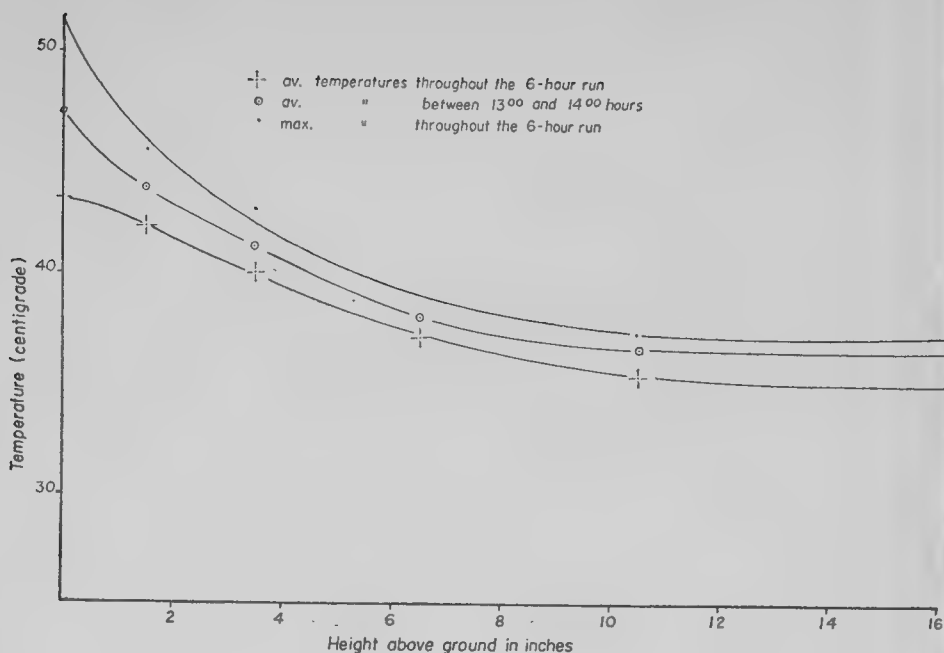


FIGURE 10.—Observed cone temperature gradients over bare mineral soil (Aug. 15th).

From the analyses of variance the effects of treatment were highly significant; *t*-tests were therefore carried out to determine the significance between treatments. The differences between the treatment means are listed for both runs.

	6-hour run	1-hour run	Significance
1.5" vs 3.5".....	2.1°	2.6°	Sig.
1.5" vs 6.5".....	5.0°	5.8°	Highly sig.
1.5" vs 10.5".....	6.7°	7.2°	Highly sig.
1.5" vs 16.5".....	6.5°	7.4°	Highly sig.
3.5" vs 6.5".....	2.9°	3.2°	Sig.
3.5" vs 10.5".....	4.6°	4.6°	Highly sig.
3.5" vs 16.5".....	4.4°	4.8°	Highly sig.
6.5" vs 10.5".....	1.7°	1.4°	Not sig.
6.5" vs 16.5".....	1.5°	1.6°	Not sig.
10.5" vs 16.5".....	-0.2°	0.2°	Not sig.

From the analyses and tests the following conclusions can be drawn.

1. The 5 thermocouples in each block recorded temperatures with sufficient uniformity to eliminate the difference between cone tissues or thermocouple installation as a source of significant variation.
2. The effects of treatment were highly significant and can be interpreted as follows:
 - a) The temperature differences between the cones at the 1.5-inch level and the 3.5-inch level are significant.

- b) The differences in temperature between those cones situated at the 1.5-inch level are highly significantly greater than those situated at the 6.5-inch level or above.
- c) The temperature differences between those cones situated at the 3.5-inch level are significantly greater than those at the 6.5-inch level, and highly significantly greater than those situated above that level.
- d) There is no significant difference between the temperatures reached by cones at the 6.5-inch, 10.5-inch and 16.5-inch levels.

The same results hold true when the data from the second run, which was conducted during one of the hottest hours of the afternoon, were analyzed.

It therefore follows that placing cone-bearing slash so that its maximum height above ground is less than $6\frac{1}{2}$ inches will result in significantly higher cone temperatures than if it is piled at a greater height. Above this $6\frac{1}{2}$ -inch level the height above ground is not significant and below this level the importance of height above ground increases as ground level is approached.

g) *Influence of Different Terrestrial Radiating Surfaces*

Since a degree of control over the nature of the terrestrial surface is possible, temperature runs were conducted on two different days on cones placed 3 inches above different radiating surfaces. Below one cone the duff surface was left undisturbed; below the second the duff was removed to expose the bare mineral soil, which in this case was of a brownish-red color; below the third the duff was removed and over the mineral soil a complete covering of black charcoal was sprinkled. The latter two surfaces can both be reproduced in actual practice by scarifying or by burning. The results obtained are presented in Figures 11 and 12.

During the first run which was on a cool day (air temperature 63°F. at 3.5-foot level) the maximum cone temperatures reached were as follows (Figure 11):

3" above charcoal radiating surface.....	36.8°C.
3" above duff radiating surface.....	33.8°C.
3" above mineral soil radiating surface.....	30.1°C.

During the second run (air temperature 72°F.) the maximum temperatures were as follows (Figure 12):

3" above charcoal radiating surface.....	48.0°C.
3" above duff radiating surface.....	46.1°C.
3" above mineral soil radiating surface.....	47.5°C.

It is obvious that the differences are not great, particularly as the temperature nears the critical range necessary for rosin bond rupturing.

DISCUSSION

From this study of fundamentals it is apparent that surface tissue temperatures of slash-borne lodgepole pine cones can be raised significantly by keeping the slash close to the ground where the cones will be under the influence of high radiation and reduced ventilation. The increases in cone tissue temperature resulting from such slash placement will not be great, but, at latitudes and altitudes where summer temperatures are seldom extreme, they can be important in effecting the release of seed from serotinous cones. Under hotter climates, such as exist in the southerly parts of the geographic range of lodgepole pine, rosin bond rupturing temperatures would not be so rare, and the attention to the lopping of slash in order to get the cones into a zone of effective temperatures not so important.

The rate of heating is of particular significance. The results suggest that a cone, and the radiating surfaces below and around it, need be influenced by solar radiation for only a few minutes in order for its surface temperature to reach a maximum for the conditions existing at that time.

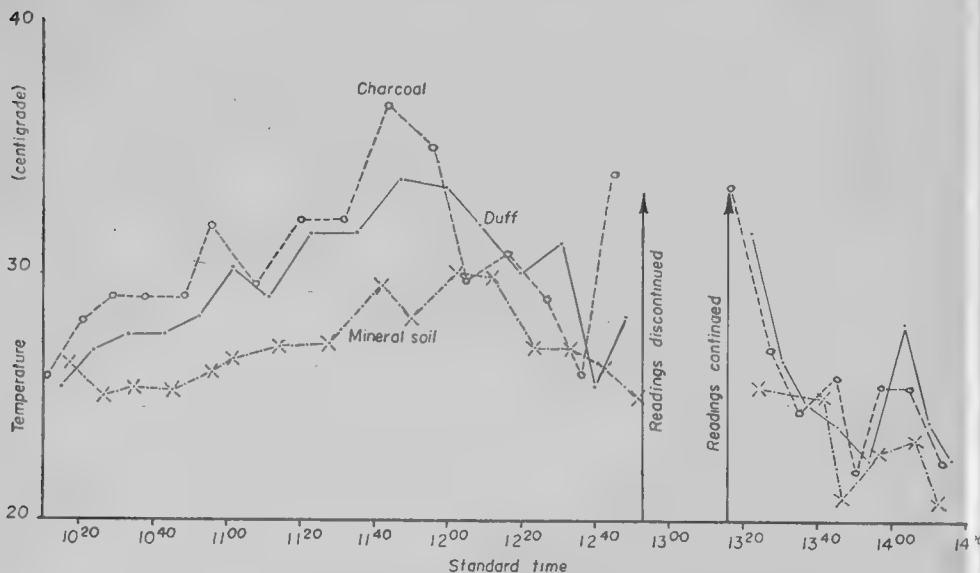


FIGURE 11.—First temperature run on three cones placed 3" above ground level, each over different type of radiating surface.

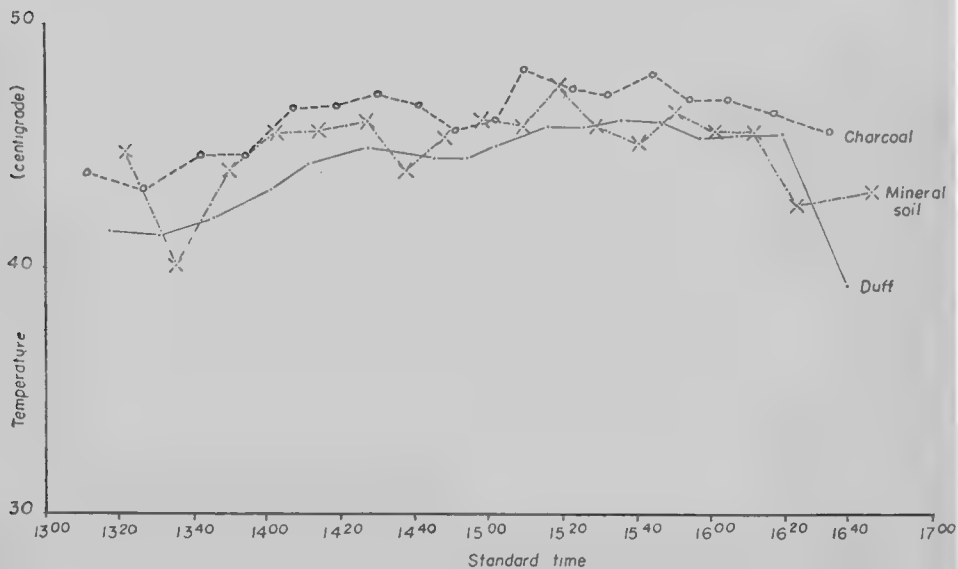


FIGURE 12.—Second temperature run on three cones placed 3" above ground level, each over different type of radiating surface.

The amount of heat radiated from the ground can be increased by providing a blackened surface such as would result from burning. However, the resulting increase in cone tissue temperatures at feasible slash levels does not appear to be sufficient to warrant such an undertaking for this purpose alone.

It is interesting to note that the maximum temperature reached in a standard instrument shelter at the 3.5-foot level located in the open on the study area between June 25th and September 11th was 87°F. Only on 6 days did the temperature exceed the 81°F. recorded on August 15th, the day when the final temperature run presented in Figure 9 was made.

Phase 2. The Behaviour of Cones in Slash After Logging

This phase of the investigation was undertaken simultaneously with the first phase, and was designed to permit an evaluation of amount and degree of cone opening and seed shedding from cones in lopped and scattered slash when subjected to varying degrees of overhead shade. The cutting areas which are part of two previously established and unrelated studies of harvest cutting methods in lodgepole pine (Crossley, 1955) are in both compartments and strips; the compartments are each ten acres in size, while the strips are 2-chain-wide clearcuts of varying length. The area is level and the site uniform, and because of the varying intensity of the residual stand remaining in the cut-over areas, it served admirably for the second phase of the study.

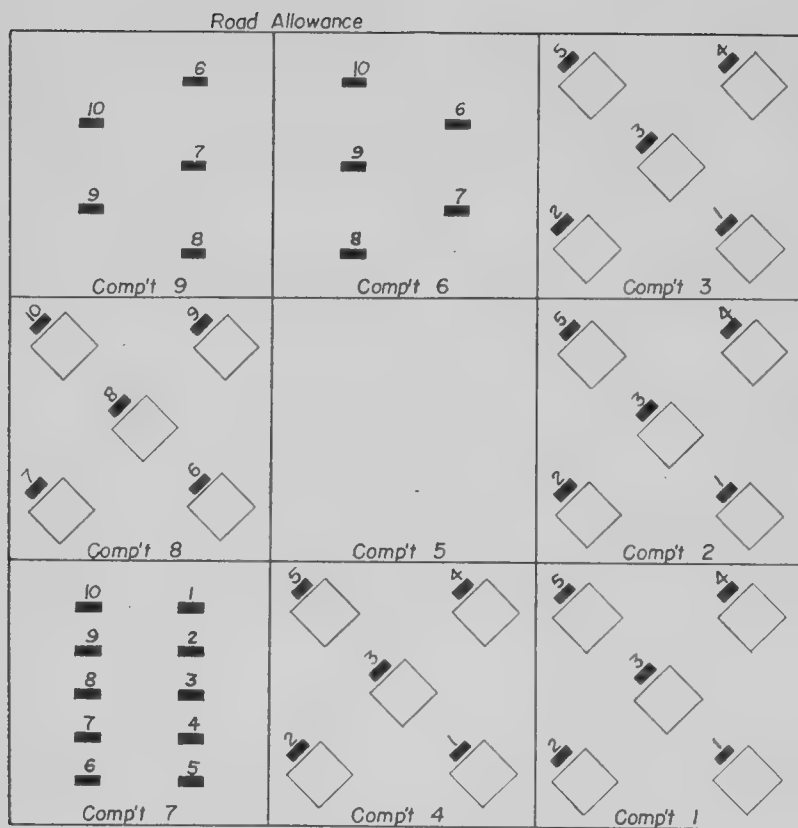
The cutting studies previously established in 1951-52 include the following:

- | | |
|------------------------|---------------------------|
| Compartment No. 1..... | thinned from below |
| “ 2..... | thinned from above |
| “ 3..... | sanitation cut |
| “ 4..... | 7-inch diameter limit cut |
| “ 5..... | control |
| “ 6..... | scattered seed tree cut |
| “ 7..... | clearcut |
| “ 8..... | shelterwood cut |
| “ 9..... | group selection |

During the winter of 1952-53 the strip cutting was completed on the area as part of another project; one-half of the strips in this study were prescarified. The cutting pattern for both projects is shown in Figure 13.

METHODS AND MATERIALS

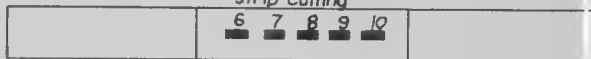
For the purposes of detailed study of cone-opening in slash under varying crown canopy intensities, five elongated milacre quadrats were laid out in each compartment. In compartments 1, 2, 3, 4, and 8 the quadrats were located on the northwest boundary of the 1/5-acre permanent sample plots established in connection with the harvest cutting studies (Figure 13). Both original stand and residual stand data are available in detail for each of these plots and therefore could be drawn upon when necessary in the present study. In compartments 6 and 7 there are no residual stands and therefore no established sample plots. The cone study quadrats were set out as shown, with ten in compartment No. 7 rather than the usual five. In compartment No. 9 each quadrat was established in the centre of a clearcutting. In order to study the effects of long-wave radiation from scarified soil, an additional five quadrats were set out on one of the scarified units in strip No. 6.



strip cutting



strip cutting



strip 6

Scale : 1" = 5 chains



p. s. p.

slash quadrat

FIGURE 13.—Diagram of quadrat layout in relation to cut-over compartments and 1/5th acre permanent sample plots.

All cone study quadrats were established in the spring of 1953. Since the original slash from the harvest cuttings was laid down at least a year previously and many of the cones had opened, it was necessary to replace it with fresh material. In order to establish the correct amount of slash per quadrat in relation to each cutting method the material removed from each of the ten quadrats in clearcut compartment No. 7 was measured and averaged, and amounted to 13 linear feet of top with unlopped branches, and an additional 4.5 feet of lopped branches. In order to simplify the operation this was regarded as 17.5 feet of top with branches and, after the removal of the old slash, this amount of fresh material was put down in each quadrat in the clearcut compartment. The amount of slash after clearcutting can be regarded as 100 per cent, and, using the comparative residual stands in the other compartments as a basis, corresponding amounts of slash were calculated and put down in them.

TABLE 2. AMOUNTS OF SLASH PLACED ON STUDY QUADRATS

Compartment No.	Linear feet of branched top per milacre
1	9.5
2	9.5
	9.0
4	4.5
6	16.5
7	17.5
8	15.5
9	9.0
Stripcut	17.5

Fresh slash was obtained from trees felled in nearby stands of the same age and density conditions, and carried into each quadrat. In each case crowns were selected in accordance with the nature of the earlier thinning or cutting. For example, slash from dominant crowns was used on the quadrats in compartment No. 2 (thinned from above) and from suppressed crowns in compartment No. 1 (thinned from below). In all cases only those crowns were chosen that bore a large majority of their cones closed. Any open cones were removed from the slash at the time it was laid down.

In order to obtain slash conditions similar to those appearing under natural conditions after logging, and to provide a variation in cone heights above ground, the slash was either lopped or piled on each quadrat. Lopping the slash consisted of removing all the branches on the upper and lower sides of the main stem so that it could lie flat to the ground, and the lopped branches were scattered as evenly as possible over the study quadrat. In no place was lopped slash allowed to exceed a height of 10 inches above the ground. In piling the slash on the remainder of the quadrats only a very slight amount of lopping was done. The usual procedure was to place one crown on top of another so that a dense mass of needles was created at one point. Slash in some places reached a maximum height of 25 inches above ground level.

Each cone to be studied was numbered with a small metal tag wired to a nearby branch and placed in such a position as to influence the heating of the cone as little as possible. Wherever any confusion was likely to arise, both cone and tag were marked with a similar spot of red paint. An attempt was made to tag 50 cones on each study quadrat, but with slash from suppressed trees this number was not always available. A total of 2,300 cones were tagged for study, with an average of 46 cones per quadrat.

Height above ground was considered an important independent variable in this study. Therefore, on one quadrat the cones were selected for tagging so that an adequate distribution of cone age classes would be available for study at various levels above the ground, and on the next quadrat so that cone exposure rather than cone age could be related to similar heights. This alternating system was followed throughout all the quadrats in each compartment. Four classes of cone exposure were adopted and the study cones were selected to comply. They were:

1. *South open.* Such cones were in position to be exposed to full sunlight for at least 4 hours during the middle of the day.
2. *North open.* Cones so positioned that they could obtain no direct sunlight between the hours of 10 a.m. and 5 p.m.
3. *Hidden.* Clusters of needles shading cones all day.
4. *Stem.* Those cones borne on the stem, or on a branch of at least the same diameter as the cone, and thus able to have a considerable effect on its heat economy.

Similarly, 4 classes of cone age were adopted. They were:

1. 1-2 years
2. 3-4 years.
3. 5-9 years.
4. 10 years or older

Using these classes the cone data could be systematized according to Tables 3 and 4 and comparable cone selections made in each compartment.

TABLE 3. RELATIONSHIP BETWEEN CONE EXPOSURE AND HEIGHT ABOVE GROUND

	South open	North open	Hidden in needles	Stem
Ground level — 1".....				
1" — 3"				
3" — 12".....				
12" + ...				

TABLE 4. RELATIONSHIP BETWEEN CONE AGE AND HEIGHT ABOVE GROUND

	1 — 2 years	3 — 4 years	5 — 9 years	10 years +
Ground level — 1".....				
1" — 3".....				
3" — 8".....				
8" +.....				

The ideal sought was 3 cones in each of the 16 possible positions, but this was not always realized. The height-above-ground scale in Table 4 differs slightly from that in Table 3 due to the fact that it was difficult to find cones in the older age classes at sufficient distance from ground level.

It will be obvious that both exposure and height above ground are bound to vary somewhat as the needles drop off and the slash settles, but these are normal factors that cannot be controlled. It is of value to have this primary information in order to note the effect of subsequent changes.

A Stevenson shelter containing a hygrothermograph for continuous standard recordings of temperature and humidity was located in a clearcut strip, together with a standard rain gauge. In addition, 8 maximum thermometers were mounted in standard shelters at the 3.5-foot level, one in each compartment, and were read and adjusted every evening.

Tallying of cone behaviour was done by breaking up the total number of quadrats into 3 series, A, B, and C, each series requiring one day to tally. In order that the data obtained could be related to the weather conditions experienced at that time, each series contained some quadrats from each compartment. It was originally intended to record steadily from day to day, but it soon became apparent that during both cold and wet periods this was a waste of time, and subsequent tallying was undertaken during warmer, drier periods where some degree of cone opening might be expected. In all, each series was completely tallied 8 times during the first field season.

Since cone opening must be measured both quantitatively and qualitatively, consideration had to be given to location of cone rupture and degree of scale flexing. For instance, it was considered that cones opening on the top surface only would be less likely to shed seed than cones opening on the bottom surface. Similarly, up to a certain point, the greater the degree of cone scale flexing the higher the percentage of contained seed that would be shed. Consequently a system of recording both "quantity" and "intensity" of cone opening was devised which was applicable to both upper and lower surfaces. By "quantity" is meant the percentage of either the upper or lower surface of the cone over which the rosin bond has broken. The "intensity" refers to the degree of scale opening, with "fully open" being considered as an angle of 100° between the cone scale and the cone's central axis. A scale of 1 to 10 was used in both cases. A pendant cone was considered as having only a lower face, and an erect cone as having only an upper face. When the whole cone had only an upper or a lower face the quantity scale was increased to 20, with the intensity scale remaining at 10.

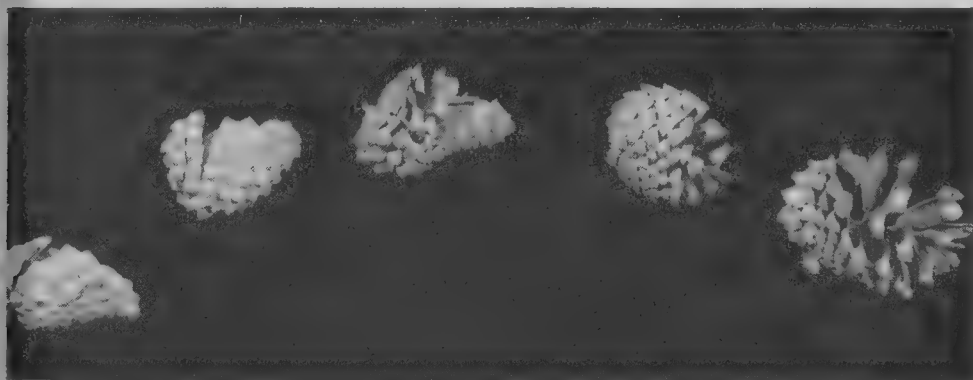


PLATE 3.—Various degrees of rosin bond rupturing and cone scale flexing.

Plate 3 serves to illustrate the technique of recording. Cones number 1 to 5 from left to right.

Example:

Cone No.	Quantity	Intensity
1	$\frac{3}{0}$	$\frac{1}{0}$
2	$\frac{5}{0}$	$\frac{3}{0}$
3	$\frac{7}{0}$	$\frac{8}{0}$
4	$\frac{10}{5}$	$\frac{6}{4}$
5	$\frac{10}{10}$	$\frac{9}{7}$

The oblique stroke in each case in the above example separates the cone's upper surface from the lower surface. The nature of the information set forth can be illustrated by cone No. 3 in Plate 3. The rosin bond has ruptured over 7/10ths (or 70 per cent) of the cone's upper surface, and still remains unruptured on its lower surface; the scales on the upper surface have flexed to an angle of approximately 80° with the cone axis. In contrast, cone No. 4 has ruptured its rosin bond completely over its upper surface, and about 50 per cent over its lower surface; the cone scales on the upper surface have flexed to an angle of approximately 60°, and to 40° on the lower surface.

The preparation of the quadrats commenced on May 18th, but the recording of the preliminary cone data on the quadrats was not completed until June 7th, (with the exception of those on compartment No. 9 and strip No. 6) so that it was not until after this latter date that the observations on cone opening could commence. Periodic collection of data during the first season continued until September 13th.

SEASONAL TEMPERATURES

Figure 14 presents the sequence of cone observations made in relation to the daily maximum air temperature readings taken at the 3·5-foot level. It will be noted that the maximum temperature readings reached highs of over 80°F. on several different occasions. The high on June 12th occurred after the quadrats on strip No. 6 had been set up, but before the cones were tagged for study. This created an unfortunate situation. Some of the cones on these quadrats on strip No. 6 had opened before tagging and recording. While such open cones were not included in the investigation, it is quite possible that their absence immediately eliminated those whose rosin bonds melted at a comparatively low temperature, and confined the study on those quadrats to the cones exhibiting higher melting points.

INFLUENCE OF CROWN COVER ON STAND TEMPERATURES

In the previous harvest cutting study (Crossley, 1955), data had been carefully collected on residual crown canopy per cents by means of readings taken with a moose-horn. Daily maximum air temperatures were taken in a standard instrument shelter at the 3·5-foot level throughout the season, and the averages of these are presented in Table 5 along with the maximum single readings reached.

TABLE 5. SEASONAL AIR TEMPERATURES AT THE 3·5-FOOT LEVEL IN RELATION TO RESIDUAL CROWN CANOPIES

Compartment	Residual Crown Canopy*	Max. Temp. Reached	Average of Daily Max. Temps.
1	27·7%	84°F	70·0°F
2	21·2	85	70·5
3	24·4	85	70·5
4	23·1	86	70·5
6	0·0 plus	—**	—**
9	0·0	86	71·5
9	14·4	86	71·0
9	0·0	85	70·0
Strip No. 6	0·0	87	72·0

* Original crown canopy averaged 44·1%.

** No temperature reading taken.

It will be noted that the maximum air temperatures recorded by sheltered thermometers at the 3·5-foot level do not exhibit much range and it is suggested that air movement is comparatively unrestricted at this level and the temperatures largely equalized by convection. The daily differences between the maximum temperatures reached under the two extremes of crown canopy are presented in Figure 15. The consistently positive figures for the clearcut compartment in comparison with those for the compartment containing the heaviest residual stand is clearly shown, even though the greatest difference of 3°F. may be considered rather small.

The second week in July was warm and clear. Figure 16 presents a reproduction of two superimposed hygrothermograph sheets, data for which were collected in compartment No. 6, which is practically clearcut, and compartment No. 1 which supports the heaviest residual stand. These data were taken at the 3·5-foot level in a standard instrument shelter and illustrate the meso-climatic differences in both temperature and humidity experienced under exposed and shaded conditions.

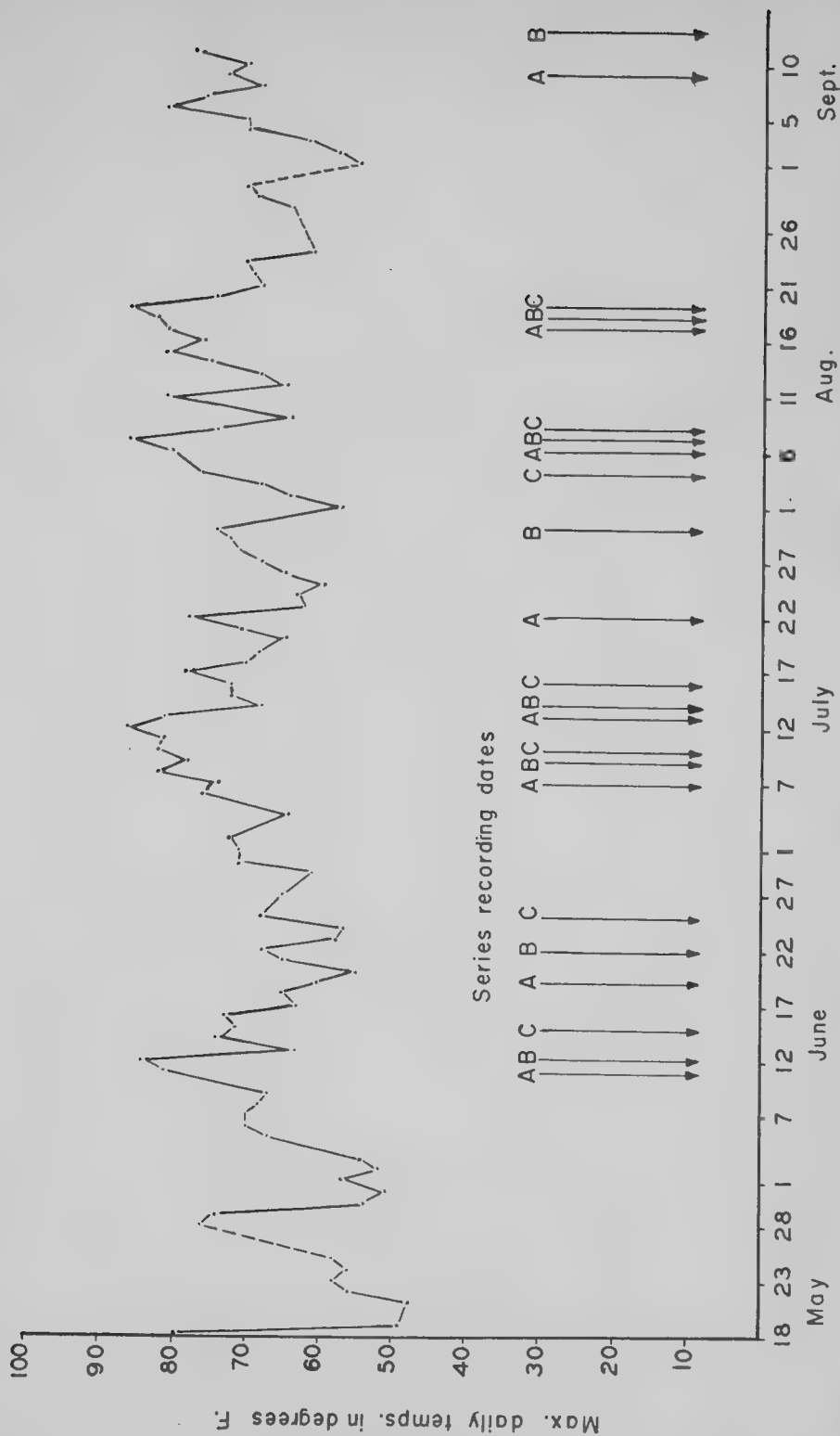


FIGURE 14.—Maximum daily temperatures obtained in standard instrument shelter located in the open, together with the data when the means of outside in each case were plotted

If the data taken at the time of incident in each case were tallied

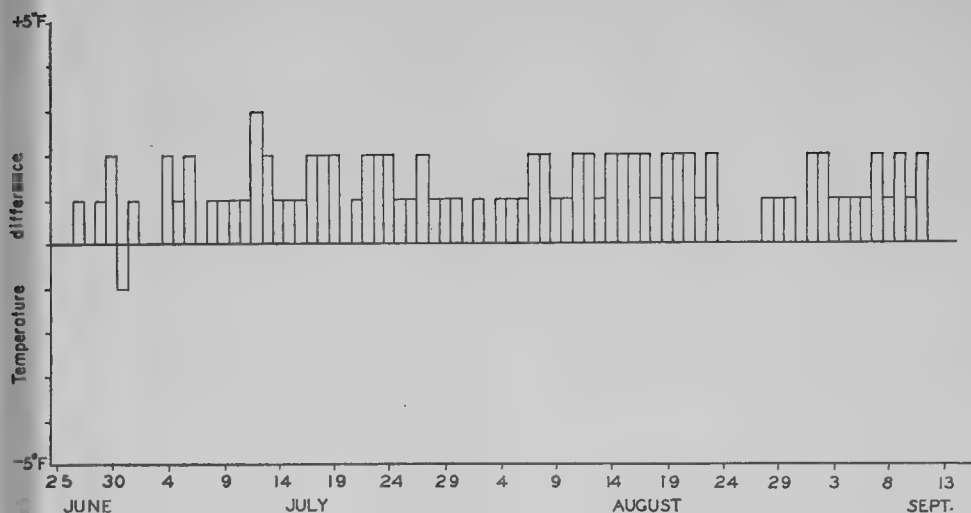


FIGURE 15.—Daily maximum temperature fluctuations in standard instrument shelter on clearcut comp't 7, in relation to similar temperatures obtained under heaviest residual stand comp't 1.

In order to obtain temperature data closer to the ground than that provided from the standard instrument shelter at the 3.5-foot level, readings were obtained* from Taylor maximum and minimum thermometers placed as close to the surface of the ground as possible (approximately one-half inch). The thermometers were shaded with a flat roof of one-foot-square plywood mounted on the peg that supported the thermometer, but allowing free air movement below. The results in four of the compartments are presented in the following table.

TABLE 6. SEASONAL AIR TEMPERATURES AT GROUND LEVEL IN RELATION TO RESIDUAL CROWN CANOPIES

Compartments	Residual Crown Canopy	Max. Temp. Reached	Av. of Daily Max. Temp.
1	27.7%	91 °F	73.7 °F
4	23.1%	90	72.4
6	0.0 plus	90	75.4
7	0.0	92	76.0

As would be expected the thermometers at ground level have registered higher temperatures than those at the higher levels (Table 5), although the range between maximums is no greater. Figure 17 illustrates the consistent increase in temperature experienced at the one-half-inch level when all effects of the shade of the overhead canopy have been removed. As in Figure 16, this difference of 5 or 6 degrees of heat may not seem of sufficient magnitude to be of much importance, but when considered in terms of radiant heat it becomes much more significant.

* Data made available from a concomitant pathological investigation by V. J. Nordin, Forest Biology Division, Science Service, Canada Department of Agriculture.

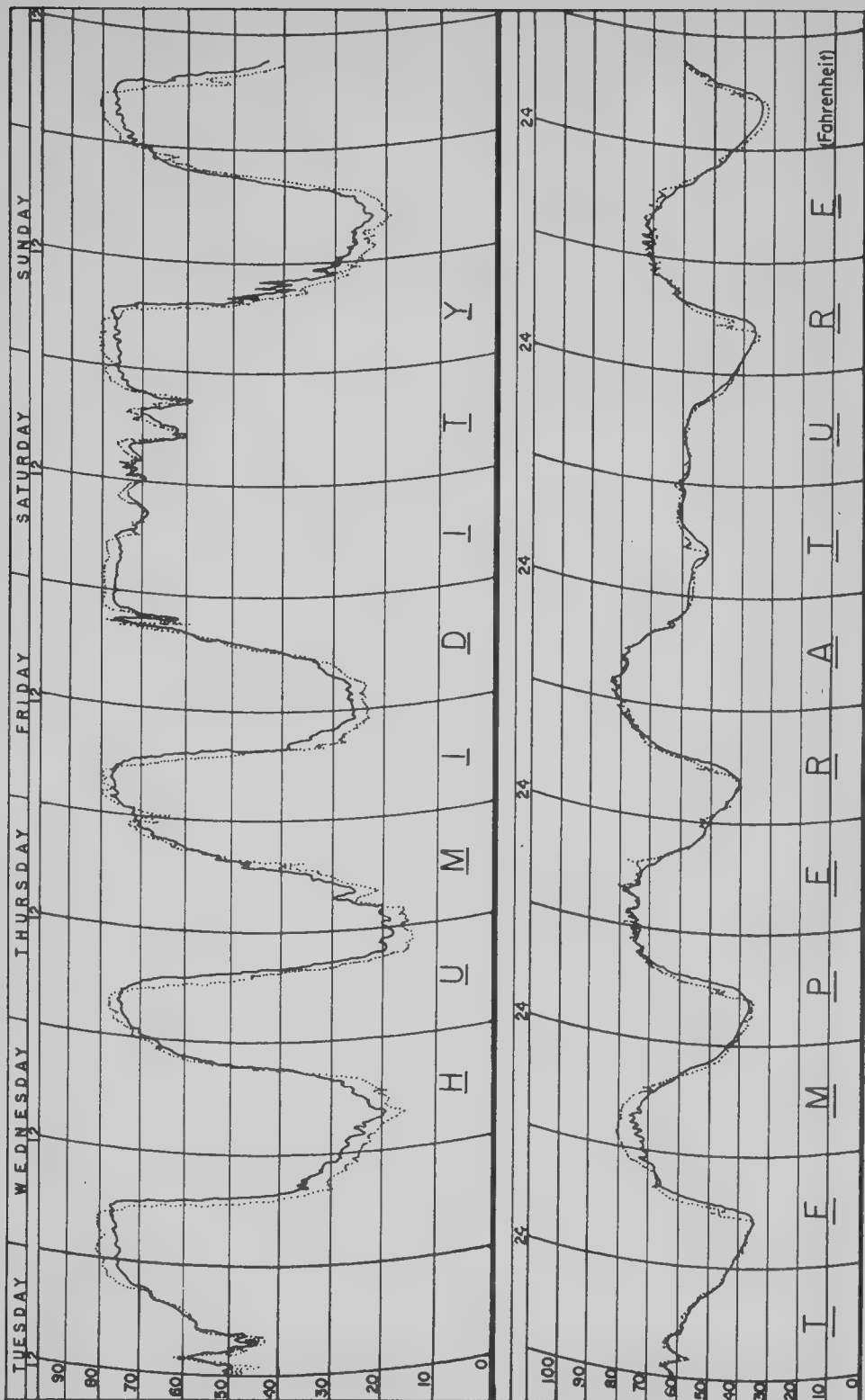


TABLE 7. SUMMARY OF CONE BEHAVIOUR IN LOGGING SLASH OVER TWO SEASONS

	Spring of 1953	Autumn of 1953	Spring of 1954	Autumn of 1954	Spring of 1953	Autumn of 1953	Spring of 1954	Autumn of 1954
Compartment No. 1								
Cones on ground.....	7.6%*	9.2%	19.5%	21.1%	12.8%	13.6%	15.5%	19.8%
Av. ht. of above-ground cones.....	5.3"	4.9"	3.7"	3.6"	5.7"	5.4"	3.9"	3.9"
Cones with rosin bond ruptured.....	—	60.0%	60.0%	69.5%	—	61.8%	61.8%	74.1%
Cones shedding seed.....	—	19.4%	—	—	—	32.0%	—	—
Cones missing.....	—	2.8%	3.7%	4.7%	—	1.6%	7.6%	13.6%
Compartment No. 2								
Cones on ground.....	14.5%	14.7%	14.2%	13.3%	0%	2.5%	15.3%	16.6%
Av. ht. of above-ground cones.....	6.4"	5.9"	4.2"	4.1"	5.3"	5.1"	4.4"	4.0"
Cones with rosin bond ruptured.....	—	59.7%	59.7%	65.8%	—	64.5%	59.7%	73.9%
Cones shedding seed.....	—	17.4%	—	—	—	16.1%	—	—
Cones missing.....	—	4.4%	6.1%	11.4%	—	2.8%	12.0%	15.3%
Compartment No. 3								
Cones on ground.....	5.0%	6.2%	16.9%	18.6%	8.4%	8.0%	16.6%	22.4%
Av. ht. of above-ground cones.....	5.3"	5.2"	3.9"	3.9"	5.2"	5.2"	3.6"	3.7"
Cones with rosin bond ruptured.....	—	51.7%	51.7%	70.6%	—	32.4%	32.4%	42.9%
Cones shedding seed.....	—	10.4%	—	—	—	6.7%	—	—
Cones missing.....	—	0.4%	2.1%	3.7%	—	0.4%	4.0%	4.4%
Compartment No. 4								
Cones on ground.....	9.8%	10.3%	20.0%	21.9%	10.8%	10.8%	13.4%	12.8%
Av. ht. of above-ground cones.....	4.4"	4.2"	2.4"	2.3"	6.1"	5.5"	4.2"	4.2"
Cones with rosin bond ruptured.....	—	55.2%	55.2%	63.3%	—	40.0%	40.0%	55.6%
Cones shedding seed.....	—	20.2%	—	—	—	14.6%	—	—
Cones missing.....	—	5.1%	7.0%	8.8%	—	0%	0.4%	2.5%
Compartment No. 6								
Cones on ground.....	7.3%	7.4%	8.0%	7.7%	8.7%	9.5%	15.9%	15.9%
Av. ht. of above-ground cones.....	6.9"	6.6"	4.9"	4.8"	5.6"	5.4"	3.8"	3.6"
Cones with rosin bond ruptured.....	—	68.8%	68.8%	72.5%	—	55.5%	55.5%	60.0%
Cones shedding seed.....	—	32.0%	—	—	—	19.9%	—	—
Cones missing.....	—	1.3%	3.4%	5.1%	—	2.0%	5.3%	8.3%
Grand Summary								
Cones on ground.....								
Av. ht. of above-ground cones.....								
Cones with rosin bond ruptured.....								
Cones shedding seed.....								
Cones missing.....								

* In all cases the percentage is of the slash-borne cones originally tagged for study.

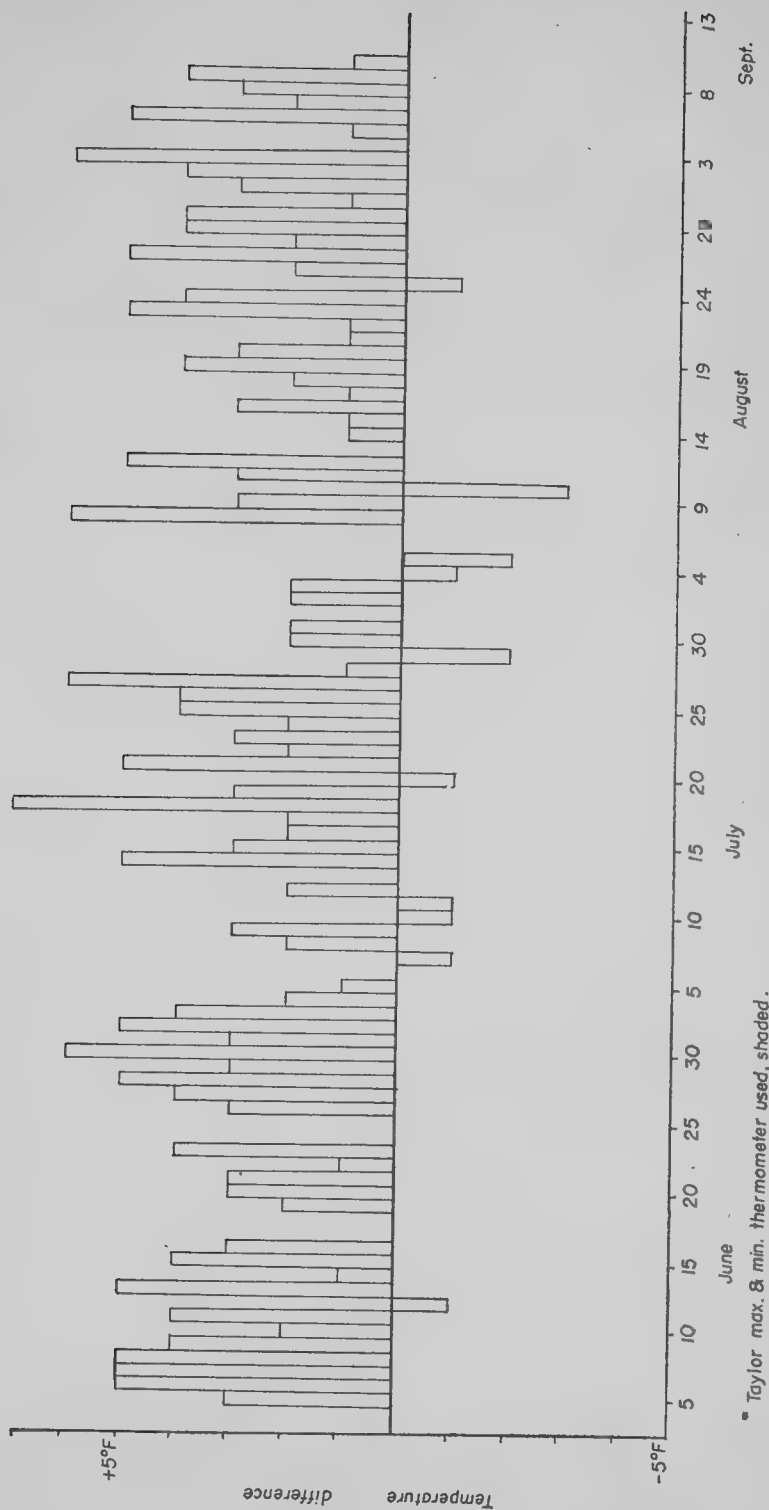


FIGURE 17.—Daily maximum temperature fluctuations at $\frac{1}{2}$ " above ground on clearcut (comp't 7) in relation to similar temperatures obtained under heaviest residual stand (comp't 1).

RESULTS

a) *Field Data on Cone Behaviour*

Cone behaviour on the study quadrats was observed over two field seasons (1953 and 1954). Since it was expected that the first season would provide most of the information sought, complete and intensive tallies were made during that period. The following field season tallies were confined to two, one in the spring and the other in the autumn. The spring tally was undertaken in order to ascertain the effects of winter temperatures and snowfall, and the autumn tally to gather sufficient information to finalize the study.

After the first season no attempt was made to collect further data on the intensity of cone scale flexing. It had been observed that the intensity of opening depends very largely on the humidity. During the collection of the first season's data this variation had largely been overcome by the system of repeated tallying of the quadrats by series. Since only one tally was to be undertaken in the spring and another in the autumn of the second season, it was felt that the degree of flexing at any one time could be misleading and such observations were not made. The results of cone behaviour are presented in Table 7.

From the results presented it is apparent that there was no increase in the percentage of cones rupturing their rosin bonds during the first winter, and that the increase in these percentages is rather insignificant during the second field season after the cone-bearing slash was laid down. Both results were to be expected. Winter temperatures would never be high enough to melt the rosin bond, and assuming similar summer temperatures during both years, additional rosin bond rupturing could only be expected following increased cone insolation resulting from shedding of dried needles and changing position as the slash settled, and to the increased effect of long-wave radiation and decreased ventilation as the cones dropped to the ground or as the slash settled closer to it.

b) *The Influence of Overhead Shade on Cone Opening*

The degree and nature of cone opening experienced in each of the compartments under study during the first summer is presented in the series of graphs designated Figures 18 to 27. They are arranged in decreasing order of residual crown canopy per cent. Those cones whose scales have flexed sufficiently wide to permit the release of the majority of their seed were recorded as having shed. Included in this series is a graph (Figure 24) similar to Figure 14, portraying the maximum daily air temperatures obtained in a standard instrument shelter located in the open.

A study of the cone opening graphs in relation to the maximum temperature graph indicates that surges in cone opening coincide fairly well with extremes in maximum temperature. During each period that the maximum standard air temperature surpassed 80°F. there was a corresponding increase in the percentage of cones rupturing their rosin bonds. However, most compartments exhibited one fairly rapid rise in percentage of cone opening about June 20th, yet on this date the season's low in maximum temperatures was experienced. While detailed information on amount of precipitation was not gathered until after the 1st of July, the records that were kept show that rainfall occurred on June 14th, 17th, 19th, 20th, and 23rd. Under such conditions the low air temperature could not have been offset by an increase in solar radiation due to air mass dryness. Consequently the possibility cannot be ignored of some secondary mechanism at work on rosin bond melting besides high temperatures. However, it seems more likely that there is a much simpler answer. At this early date the field crew may not have been proficient in recognizing when each cone's rosin bond had ruptured.

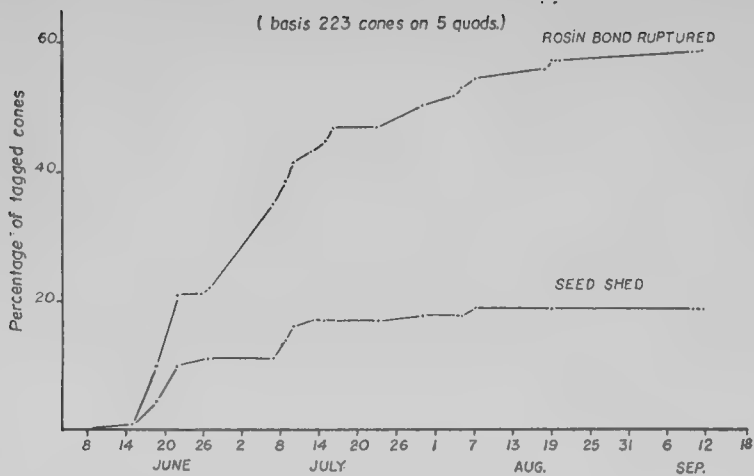


FIGURE 18.—Comp't 1—28% crown canopy.

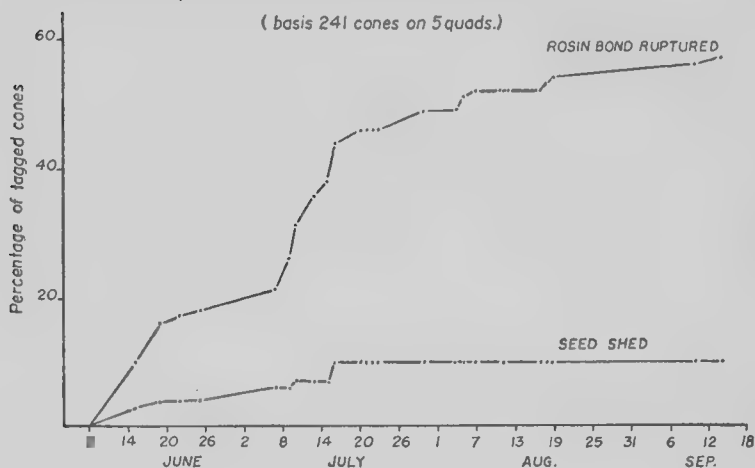


FIGURE 19.—Comp't 3—24% crown canopy.

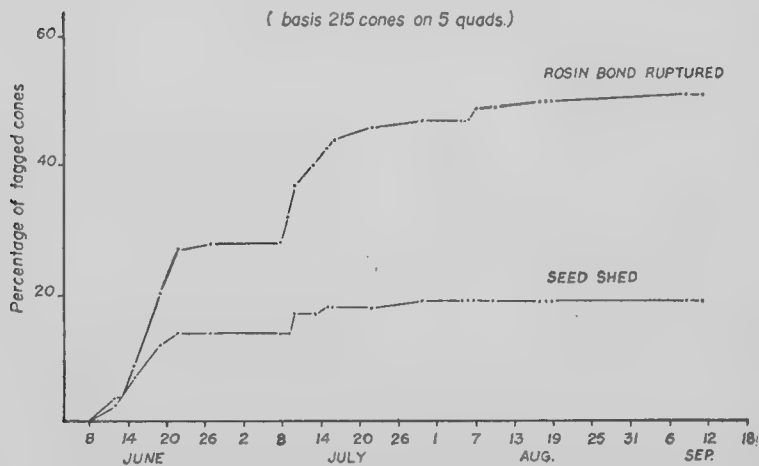


FIGURE 20.—Comp't 4—23% crown canopy.

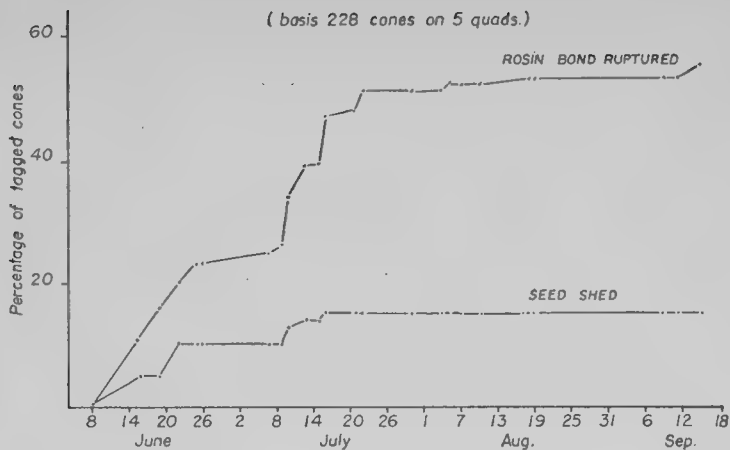


FIGURE 21.—Comp't 2—21% crown canopy.

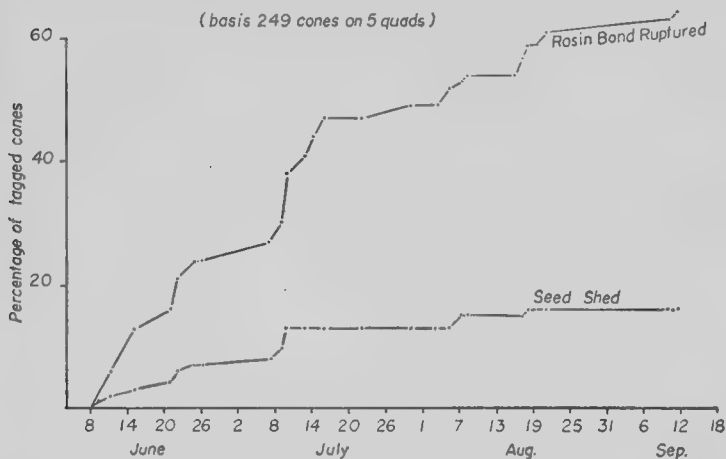


FIGURE 22.—Comp't 8—14% crown canopy.

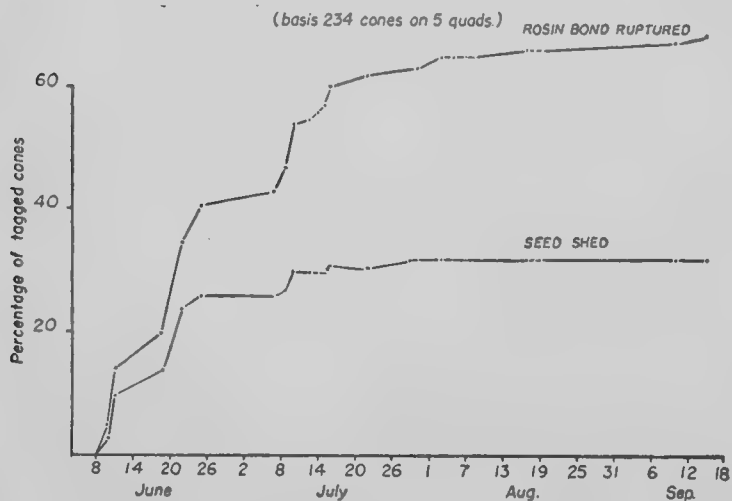


FIGURE 23.—Comp't 6—Seed tree cut.

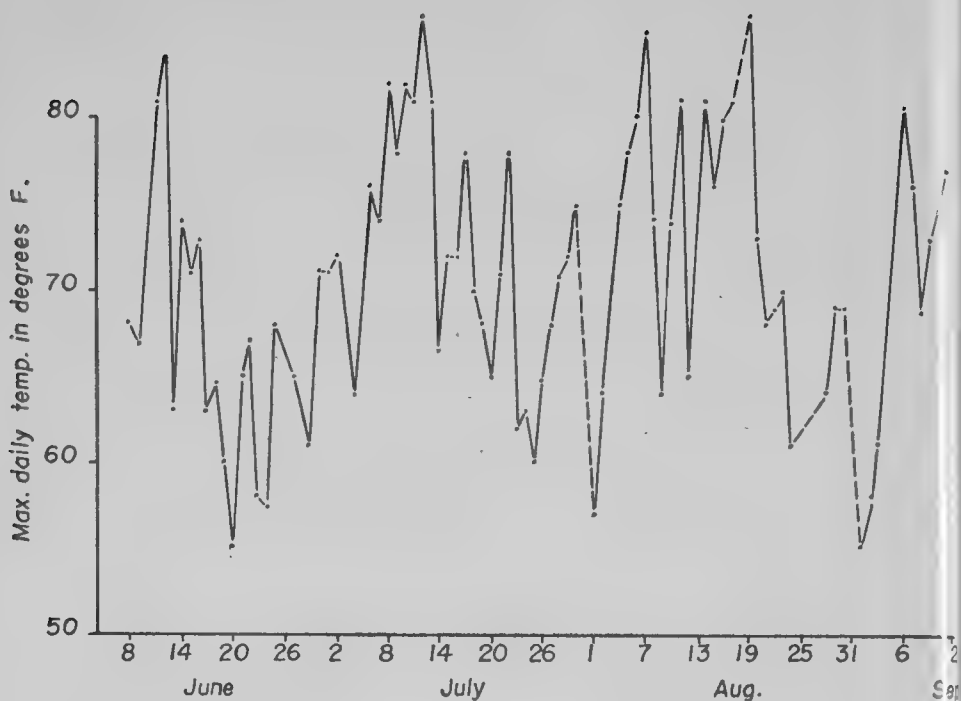


FIGURE 24.—Maximum daily temperatures obtained in a standard instrument shelter in the open.

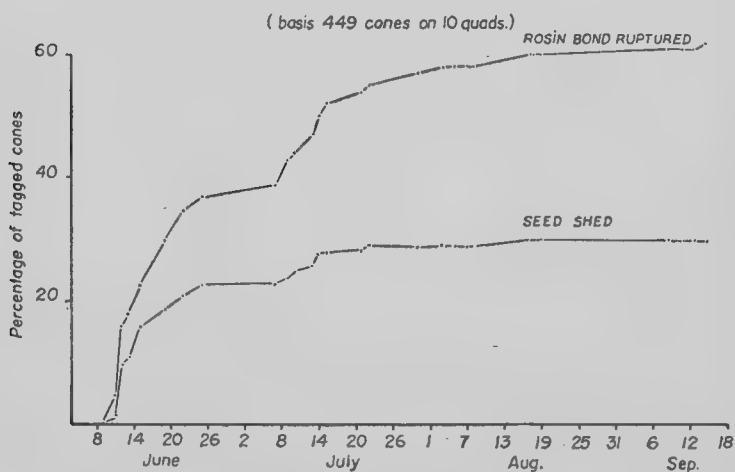


FIGURE 25.—Comp't 7—clearcut.

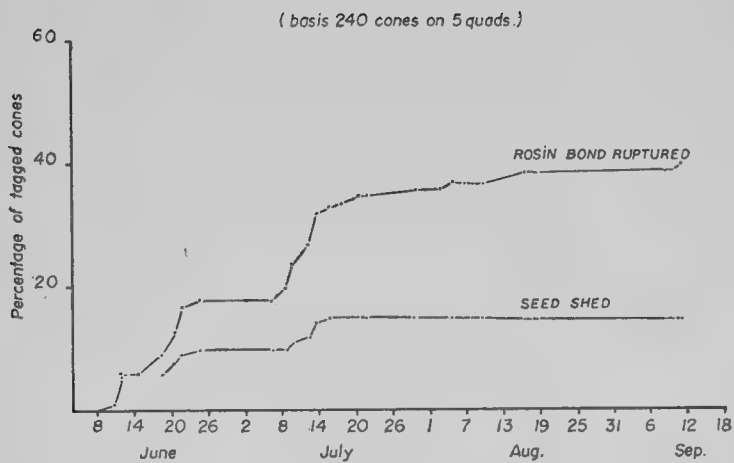


FIGURE 26.—Strip 6—clearcut.

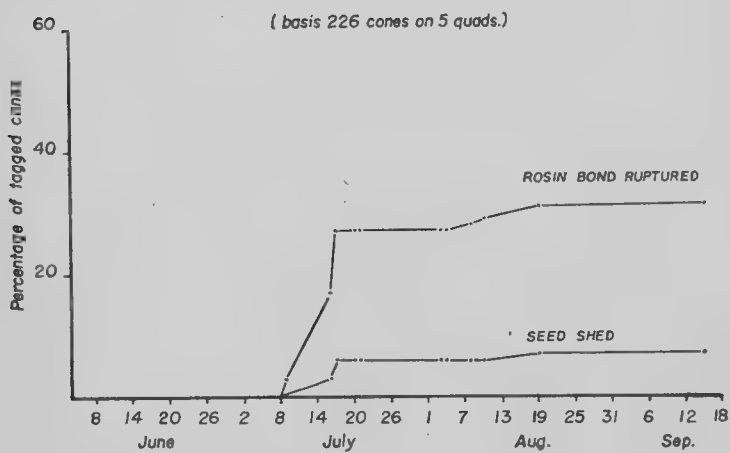


FIGURE 27.—Comp't 9—clearcut in small patches.

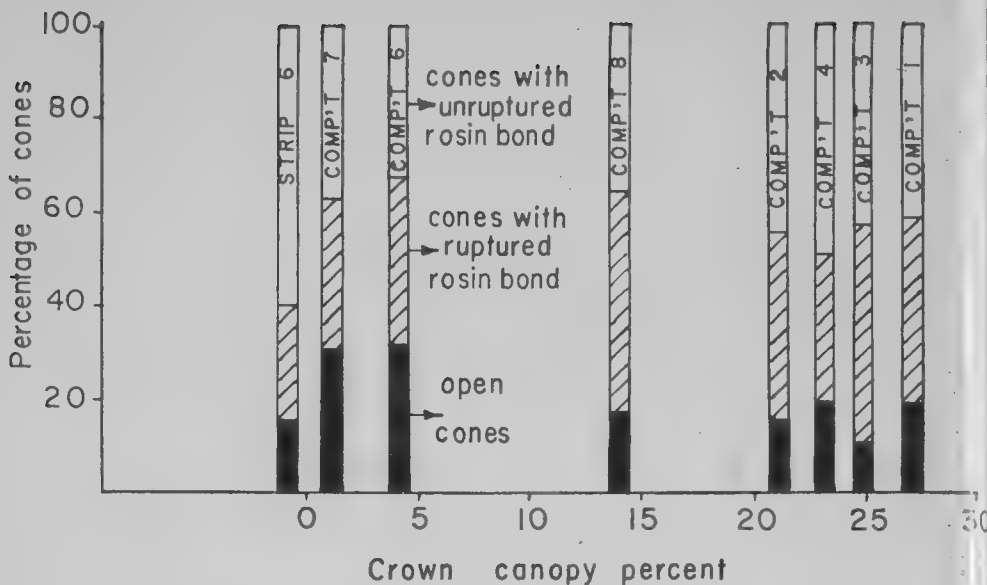


FIGURE 28.—Relationship between residual crown canopy and cone opening.

High humidity after rupturing will cause the cone scales to close tightly. Experience taught the observers under such conditions to test for rupturing by inserting the thumb nail under the scales, or by squeezing the cone and watching carefully for movement of one scale over another. The suggestion therefore is that many cones ruptured under the high temperatures experienced on June 12th and 13th but because of the humid conditions immediately following they were not all recognized at once, and the percentage of cones rupturing that should have been credited to this initial temperature surge may have been spread over the ensuing week or ten days.

Cones were laid down in compartment No. 9 a month later than on the other compartments and a strict comparison is therefore not possible.

In order to make an easier comparison between the effect of residual crown canopies, the first season's results are summarized in Figure 28. The bar graphs are arranged in increasing order of residual crown canopies and (with the exception of strip No. 6 which is a special case to be discussed later) it appears that increasing crown canopy has only a small, although consistent, repressive effect on the initial rupturing of the rosin bond. Since it has already been shown that only a very short period of direct radiation is necessary to raise the cone's temperature to a critical level, such results are to be expected. Unless the crown canopy is nearly complete, the direct rays of the sun have repeated access to the slash below for short intervals of time.

Once the rosin bond is ruptured the initial degree of cone scale flexing depends upon the proximity of the cone to the earth's radiating surface and to the ventilation the cone receives. One would expect that under clearcut conditions ventilation would be at a maximum, more rapid flexing would result, and therefore a maximum amount of seed would be shed during the first season. As depicted graphically in Figure 28, this appears to be the case. Comparing the seed-shedding results in compartments 1 and 3 which have the heaviest residual canopy, with compartments 6 and 7 which are, for all practical purposes, free of overhead shade, the former exhibit 14.6 per cent of their cones with scales flexed sufficiently to shed all the seed at the conclusion of the first season, and the latter 32.0 per cent.

Since the underside of the cone is unaffected by direct solar radiation, the issue temperatures reached here will be lower than those attained on the upper surface. At the conclusion of the first summer, 1,074 of the original 2,300 cones had ruptured their bonds to some degree. The average "quantity" of rupturing in these 1,074 cones was 68.2 per cent of the upper surface, and 46.1 per cent of the lower surface. It is interesting to note that the "intensity" of cone scale flexing was also less on the lower surface of the cone than on its upper. The average maximum flexing on the upper surface at the conclusion of the first summer's observations was 32° from the central axis of the cone, and on the lower surface 17°. It is therefore apparent that most of the seed falling to the forest floor during the first summer season was supplied from the upper surface of the cone.

In spite of a common absence of overhead shade and a similarity in slash conditions in strip No. 6 and compartment No. 7, the results in cone opening (Figure 28) are quite dissimilar and are therefore worthy of comment. The only obvious physical difference in conditions on the two areas is the scarified soil on strip No. 6, and the comparatively untouched forest floor in compartment No. 7. The bare mineral soil may have had some effect in reducing the radiant heat, although this principle was not consistently borne out when it was specifically investigated in Phase 1 of the study (Figures 11 and 12). It seems more likely that the discrepancy in results can be explained by the nature of the cones under observation. It will be recalled that the cones on strip No. 6 were not prepared for observation until the first spring surge in temperature had opened some of the cones. It was suggested that this may have removed from the study those cones whose rosin bonds melted at a comparatively low temperature, and confined it to a sample of cones not comparable to the samples in all the other compartments.

3) Influence of Height Above Ground on Cone Opening and Seed Shedding

Figures 29 and 30 present freehand lines approximating the linear regression relationships between cone opening and height above ground. Figure 29 presents the relationship under clearcut conditions when overhead shade is lacking, and Figure 30 under the shade of residual stands. In each figure the upper line represents the relationship between rosin bond rupturing and cone height above ground, and the lower line the relationship between cone scales flexing sufficiently to release all or most of the contained seed and height above ground.

The slope of these regression lines would have been even steeper had it been possible to eliminate from the data those cones that ruptured their rosin bonds because they were within the influence of radiating surfaces other than the ground. Many cones situated at a considerable height above the ground were found open and almost invariably the suggested explanation was their proximity to the radiating surface of a heavy branch or bole. Similarly, most of the cones close to the ground that did not open were situated in locations where they were continually shaded.

The information presented in Figures 29 and 30 supports the significant relationship between height above ground and cone opening that resulted from the fundamental study (Phase 1); that is, the closer the cone is to the ground the greater are its chances of reaching temperatures critical to the rupturing of the rosin bond. The regression lines intended to express the relationship between height above ground and the percentage of cones that have flexed their scales sufficiently during the first season to permit seed shedding illustrate the same thing. This suggests that the increase in evaporation of moisture due to increased heat more than offsets the reduction in evaporation due to decreasing ventilation as ground level is approached.

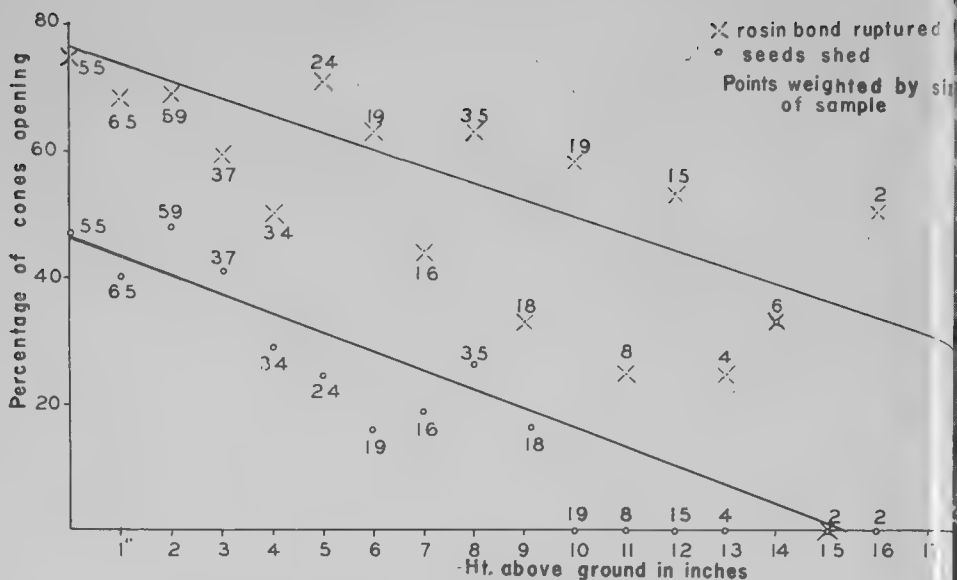


FIGURE 29.—Relationship between cone opening and height above ground under clearcut conditions in comp't 6, 7 and strip 6.

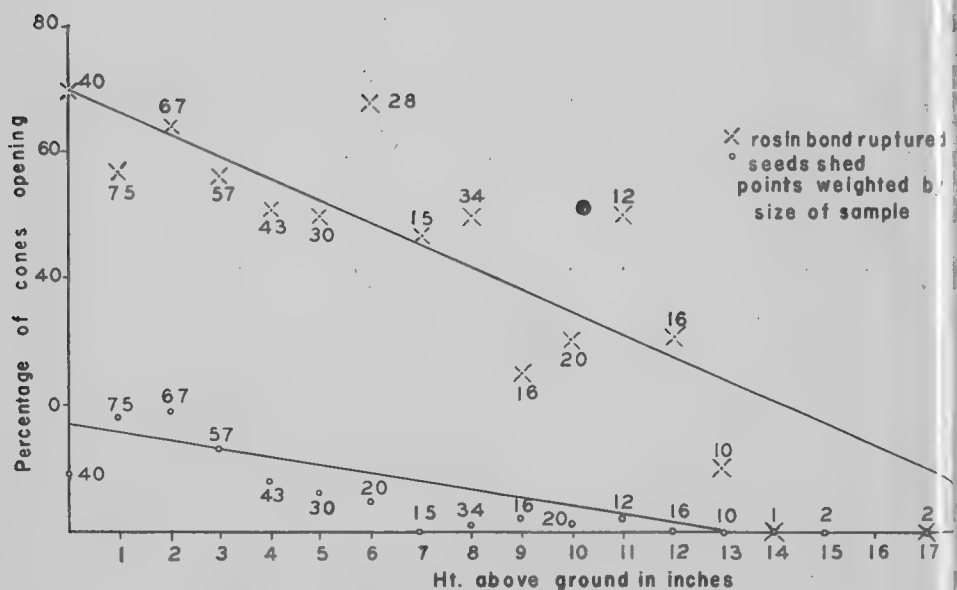


FIGURE 30.—Relationship between cone opening and height above ground under residual stands comp't 1, 2, 3, 4.



PLATE 4.—Cone opening in relation to height above ground.

When the effect of overhead shade on cone behaviour is considered, it is apparent from the information presented that the absence of a residual crown canopy has resulted in the highest percentage of both rosin bond rupturing and cone scale flexing. If 50 per cent or more of the cones rupturing is accepted as an arbitrary objective at the conclusion of the first season, then this goal was obtained under clearcutting in those cones 9·8 inches or less above ground level, while under residual stands such a goal was obtained among those cones 6·4 inches or less above the ground. Expressed another way, under clearcut conditions approximately 58 per cent of the cones 6·5 inches or less from the ground ruptured their rosin bonds, and only 46 per cent of similarly placed cones under residual stands.

Similarly, if we accept an arbitrary figure of 25 per cent as a goal for cones shedding seed during the first season, this was obtained among those borne 7 inches or less above the surface of the ground under clearcut conditions, but not attained at all at similar levels under the residual stands.

Clearcut conditions resulted in higher temperatures and less restricted ventilation, but it should not be inferred from the results of the first season's observations that there will be any less ultimate flexing of the cone scales once the rosin bond is ruptured under overhead shade. Later observations indicate that once the rosin bond is ruptured the scales will eventually flex. However, the rate of flexing and therefore the rate of seedfall is hastened as heating and ventilation are increased by the elimination of crown canopy shade.

d) The Effect of Exposure on Cone Opening

When the cones were selected on each quadrat for study, their exposures were noted and tallied according to whether they were subject to direct solar radiation during the heat of the day, hidden from direct radiation but otherwise

in the open, or hidden from the upper hemisphere by needle masses and branches. The results in terms of ruptured rosin bonds are presented in the following table.

TABLE 8. THE PERCENTAGE OF CONES WHOSE ROSIN BONDS RUPTURED DURING THE FIRST SEASON IN RELATION TO CONE EXPOSURE

Compartment No.	Exposed to South	Exposed to North	Hidden
1	69	61	65
2	63	55	51
3	61	43	48
4	63	48	59
6	72	74	51
7	66	50	61
8	72	56	59
9	42	39	21
Strip No. 6	45	27	31
Average	64	51	49

It is apparent that exposure to direct radiation has resulted in an increase in rosin bond rupturing, but such exposure is by no means a criterion of success. Because of the compartmental variation in rupturing expressed in the last two columns in Table 8, it is suggested that the differences obtained are non-significant. This is to be expected since in neither case were the cones subject to direct radiation. The reason why a considerable percentage of those cones exposed to the north or hidden from the upper hemisphere ruptured their rosin bonds is not obvious. Such cones were usually in slash pockets and under these conditions the heat resulting from long-wave radiation from the ground and nearby radiating surfaces may have been sufficient to raise the rosin bond temperature to the critical point. In such cases the heat lost by conduction and convection is minimized as a result of the reduced air ventilation. Further, the volume of air around the cone is small compared with the surface area of the slash surrounding it, and the temperature gradient is therefore minimized. On the other hand, it will be recalled from the results presented in Phase I of this study that very few minutes of direct exposure to solar radiation was sufficient to effect rupture of the rosin bond, provided that conditions were otherwise right. It may therefore be that many of the cones classified as "exposed to the north" or "hidden" may not have been entirely so and therefore may have received short intervals of direct solar radiation sufficient to rupture their bonds. Such an eventuality could result either from an unawareness at the time of cone classification that even a very short interval of direct exposure might be effective or from changes in cone exposure throughout the summer as the slash dried and the needles dropped.

e) The Effect of Cone Age on Opening

TABLE 9. THE PERCENTAGE OF CONES WHOSE ROSIN BOND RUPTURED DURING THE FIRST SEASON IN RELATION TO CONE AGE

Compartment No.	1-2 years	3-4 years	5-9 years	10 years
1	56	58	63	60
2	63	49	57	53
3	42	45	61	63
4	68	50	33	53
6	64	73	72	68
7	52	52	73	71
8	66	58	66	58
9	28	13	30	26
Strip No. 6	32	42	46	45
Average	51	51	56	56

Clements (1910) stated as a general rule that there appeared to be two periods of opening for lodgepole pine cones in standing trees. He wrote: "The first period comprises several years immediately following maturity, and the second falls between the 10th and 15th years". This is qualified by a statement to the effect that it is usual for one of these periods to be much more marked than another in a particular region. In the present study no slash was used from trees bearing open cones and Clements' first period was therefore eliminated. The data presented in Table 9 do not suggest any marked increase in rate of rosin bond rupturing after the tenth year under slash conditions.

f) The Effect of Time Since Logging (or Slash Age) on Cone Opening

The average height above ground of the study cones at the time the slash was laid on the milacre quadrats was 5.6 inches. At the end of the first field season the average height had decreased to 5.4 inches as the slash settled. The winter snows depressed the slash still further, and in the spring of the year average cone height was 3.9 inches. By the autumn of the second season a further slight decrease put the cones at an average height of 3.6 inches above ground. This gradual decrease in height meant higher cone temperatures due to the increased effect of long-wave radiation as well as reduced ventilation at these levels. Many cones originally too high in slash to reach critical temperatures for rosin bond rupturing will move to lower levels and rupture and release seed at a later date.

In this connection Tackle (1954), reporting on the viability of lodgepole pine seed stored in unopened cones in logging slash, states that much of the seed remains viable for at least 6 years, but that the seed borne by those cones in contact with the ground, presumably for a similar length of time, exhibited only half the germinative capacity of the seed borne in above-ground cones.

g) Cone Loss

The steady increase in tagged cones missing from the study is explained chiefly by the depredations of rodents. The loss is not large but it is of course confined to the cones that still retain their seed, and the reserve supply of seeds is therefore being steadily depleted. After the first summer it is likely that the cones taken are chiefly those whose rosin has a comparatively high melting point and thus resist rupturing, or are so placed in the slash that they are unlikely to receive sufficient heat to enable them to rupture their rosin bonds.

DISCUSSION AND CONCLUSIONS

Critical temperatures for the rupturing of the rosin bond appear to lie within the range of 45-50°C. In order to obtain such temperatures within the zone 0 to 6.5 inches above the ground surface under slash conditions, it is suggested that standard air temperatures at the 3.5-foot level of at least 80°F. must be reached. However, all cones so placed do not rupture their bonds when such air temperatures are reached due to the fact that shade, distance from radiating surfaces, and ventilation play important parts. As time goes on and needles drop and slash settles, all these factors can change, and the usual result will be more exposure to solar and terrestrial radiation, and a decrease in ventilation, so that those cones that have retained their rosin bonds unruptured during the first season will generally find themselves under higher temperature conditions the following year and thus less likely to resist rupturing. Tackle (1954) suggests that increased stocking of lodgepole pine seedlings can result from such a source or as long as the seed remains viable under such storage conditions. It is doubtful if any significant increase in stocking could be expected, however, because it is not likely that there will be any appreciable change in cone radi-

ation, height above ground, or ventilation, after the second or third year, and such changes are necessary if the rosin bond is to rupture. Eyre and LeBar (1944), working in jack pine stands in the Lake States, report that seed was dispersed freely from cones in lopped and scattered slash during the midsummer period of the first two years, but only to a slight extent during the third year.

Once the rosin bond has ruptured, the release of seed from the cone is effected by the spreading of the scales. As the bond ruptures a distinct sound can usually be heard, suggesting that there is an internal physical force attempting to flex the scales away from the central axis of the cone. This initial flexing does not result in sufficient spread to release any seed, and further spread must await the drying out of the internal parts of the cone. The degree of flexing therefore depends upon the degree of drying, or upon the humidity of the enveloping air. Consequently there is considerable movement of the cone scales back and forth with changing humidities. Wide open cones can close almost completely in a matter of hours during a period of maximum atmospheric humidity. Such flexing back and forth of the cone scales results in the working of seed out of the cone. In this fashion, seeds on the upper surface of cones are slowly forced out and allowed to fall upon the ground. Under artificial seed extraction methods, seed release is hastened by shaking the cone. Under field conditions where the time element is not so important, the same end is eventually reached as a result of the natural fluctuations in atmospheric humidity.

Since the density of regeneration of lodgepole pine is a major problem in its management, some degree of control over seedfall is of utmost importance and it is apparent that under suitable harvest cutting methods slash disposal can provide this control. Slash density and slash depth can both be controlled and therefore the amount of seed that will reach the seedbed is likewise controllable.

The fact that the cones in direct contact with the surface of the ground exhibited the highest rate of rosin bond rupturing and cone scale flexing is worth noting. One very practical method suggested for harvesting lodgepole pine is clearcutting, with the slash windrowed for burning by the use of a bulldozer blade. The result of such treatment is to leave a scarified seedbed of scattered cones that have broken off from the transported slash. These cones are then in the ideal location for rosin bond rupturing and seed dissemination.

The results obtained generally indicate that the amount of seed released from cone-bearing slash during the first and second season following cutting increased with decreasing overhead shade. Consequently, if maximum amount of seed are required on the forest floor within this period it will be necessary to lop the slash closer to the ground as the amount of overhead shade increases. However, when dealing with such an intolerant species as lodgepole pine it is obvious that, under conditions of overhead shade, a point will soon be reached where low light intensity at the forest floor will result in unacceptable growth of seedlings. It would be an objective for future research to find out what maximum degree of overhead shade would result in acceptable seedling growth and what amount of lopping would be necessary under those conditions to effect an acceptable degree of stocking.

Since the rate of heating of the cones' tissues is partially dependent upon terrestrial radiation, reflected solar radiation and molecular heat conduction from the soil surface, it follows that such rate of heating is also dependent upon the exposure of the soil surface and the angle it presents to the sun. Therefore maximum heat will be available from these sources to cones situated on south-facing slopes at right angles to the sun's rays during the heat of the day, and minimum heat on northerly slopes. Consequently, similar seed cast on both slopes will require a manipulation in slash levels.

SUMMARY

In order to investigate the natural release of seed from serotinous cones borne on lodgepole pine slash, and the effect of varying degrees of overhead shade cast by residual stand crown canopies, an investigation was undertaken in an 85-year-old stand in western Alberta where a variety of harvest cuttings provided the necessary study conditions. The investigation was divided into two phases.

1. A fundamental study of comparative cone tissue temperatures reached throughout the day under maximum conditions of solar radiation by cones situated at various levels above the ground. Fairly precise temperature readings were obtained through the use of fine wire thermocouples embedded within the cone tissue.
2. An applied study of the behaviour of slash-borne cones in relation to seed release when situated under varying degrees of overhead shade.

The results of Phase 1 of the study may be summarized as follows:

1. By means of fine wire thermocouples, cone tissue temperatures can be read with sufficient accuracy to provide data that will permit comparisons between cones subject to different degrees of heating.
2. Maximum cone tissue temperatures were reached between 1300 and 1500 hours, standard time.
3. In general, standard air temperatures at the 3.5-foot level of at least 80°F. (26.6°C.) are necessary before cones in the layer near the ground are heated sufficiently to result in rupturing of the rosin bond.
4. Once a cone is subjected to direct solar radiation its rate of heating is very rapid. Normal crown openings in a thinned stand of lodgepole pine would usually allow the direct rays of the sun to reach an exposed cone in the slash for a sufficient length of time to heat it to a maximum for conditions as they exist at that time.
5. The closer the cones borne by the slash are to the ground (or any large reflecting surface close by) the greater the temperature they will attain, but under the levels investigated in this study, there was no significant difference in the temperature attained by the cones 6.5 inches above the ground and higher. Therefore, if advantage is to be taken of the earth's radiating surface to effect cone opening, slash should be placed so that the maximum number of cones are situated below this 6.5-inch level.
6. A black radiating surface, such as the forest floor after a fire, was more effective than either a reddish-brown mineral soil or the undisturbed duff in increasing the temperature of cones 3 inches above, but in no case were differences of any magnitude.

The results of the applied study (Phase 2) of slash-borne cones in relation to seed shedding under varying degrees of overhead shade support the conclusion arrived at from the preceding fundamental study, and additional results of this second phase are summarized below.

7. Although the differences were not great, standard air temperatures at the 3.5-foot level were consistently higher under clearcut conditions and lowest under the heaviest residual stand. The same is true of the higher temperatures obtained at a level one-half-inch above the ground.
8. The rate of rosin bond rupturing and cone scale flexing increases with the decrease in overhead shade and with proximity to the ground. Consequently the amount of seed reaching the forest floor at an early

- date will be at a maximum under clearcut conditions and where slash is lopped and well scattered so that the cones are as close to ground as possible.
9. Cones in direct contact with the ground rupture their rosin bonds and flex the scales on their upper surface at a faster rate than cones situated in the slash above.
 10. The upper surface of a slash-borne cone ruptured its bond, flexed scales and therefore shed more seed during the first summer season than did the lower surface.
 11. Seed is released from the opened cone due to the "working" effect of the flexing scales. The nature and the degree of flexing in turn depend upon natural variations in atmospheric humidity.
 12. Once the rosin bond is ruptured the initial degree of cone scale flex depends upon the proximity of the cone to the earth's radiating surface and to the ventilation, which in turn depends upon the density of the residual stand. Eventually, however, with repeated wettings and dryings, the degree of flexing should be quite similar under all conditions.
 13. Under the climatic conditions experienced during the two years of the study the greatest amount of seed was shed during the first summer season. It was therefore available for germination on the forest floor the following spring. Seedfall the second season was considerably less and was apparently released from cones whose proximity to a radiating surface, or whose degree of exposure, had become more favorable during the intervening period. It is suggested that any further addition of seed in subsequent years from the remaining unopened cones would be negligible, since no further appreciable differences could be expected that would result in the necessary increase in heating.
 14. Age of the cone appears to have little relation to the ease of rosin bond rupturing. At the conclusion of the first summer season, 51 per cent of the 1- to 4-year-old cones had opened compared to 56 per cent of cones more than 10 years of age.
 15. There is a small but steady loss of unopened cones from the slash that can be explained only by the depredations of rodents.
 16. The more overhead shade provided by the residual stand the less must the cone-bearing slash be lopped if sufficient seed is to be released to result in any chosen degree of regeneration stocking.
 17. Maximum radiation will result on southerly slopes at right angles to the sun's rays at noon, and minimum radiation on northerly slopes. Similar seed cast on both slopes will require manipulation of slash level.

REFERENCES

- CAMERON, HUGH. 1953. Melting point of the bonding material in lodgepole pine and jack pine cones. Canada, Dept. Northern Affairs and National Resources, Forestry Branch, For. Res. Div., Silv. Leaflet No. 86.
- CLEMENTS, F. E. 1910. Life history of lodgepole pine burn forests. U.S. Forest Service, Bull. No. 79.
- CROSSLEY, D. I. 1955. Lodgepole pine studies at the Strachan Experimental Block in Alberta. Canada, Dept. Northern Affairs and National Resources, Forestry Branch, For. Res. Div., Tech. Note No. 19.
- EGGERT, RUSSELL. 1946. The construction and installation of thermocouples for biological research. Jour. Agric. Research, Vol. 72, No. 11.
- EYRE, F. H. and R. K. LEBARRON. 1944. Management of jack pine stands in the Lake States. U.S. Dept. Agriculture, Tech. Bull. No. 863.
- GEIGER, R. 1950. The climate near the ground. Trans. by Milroy N. Stewart *et al.* Harvard University Press.
- LEBARRON, R. K. and E. I. ROE. 1945. Hastening the extraction of jack pine seeds. J. For. 43 (11).
- TACKLE, DAVID. 1954. Viability of lodgepole pine seed after natural storage in slash. Intermountain Forest and Range Experiment Station, Ogden, Utah. Res. Note No. 8.

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SLASH DENSITY ON THE RELEASE
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